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Lewis Caerleon and the equation of time: tabular astronomical practices in late fifteenth-century England

Laure Miolo[1] · **Stefan Zieme**[2]

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Abstract

The manuscripts and writings of the fifteenth-century astronomer and physician Lewis Caerleon (d. *c.* 1495) have been largely overlooked. To fill this gap, this article focuses on his writings and working methods through a case study of his canons and table for the equation of time. In the first part, an account of his life and writings is given on the basis of new evidence. The context in which his work on the equation of time was produced is explored in detail by reviewing the three key periods of his scientific production. His heavy reliance on Simon Bredon's *Commentum super Almagesti* is also analyzed. The article also provides editions of Lewis Caerleon's canons for calculating his table for the equation of time and a critical edition of Simon Bredon's *Commentum super Almagesti,* III, 22–24. In the second part of this article, we analyze the table for the equation of time derived by Lewis around 1485. In addition to the final table, there is a unique table with intermediate results that records every step of his derivation. By following and discussing the details of this derivation, we shed a new light on tabular practices in mathematical astronomy. Following Lewis in his historical mathematical procedure, we argue, offers a novel historiographical approach that allows us to identify different sources and practices used by historical actors. Therefore, beyond the exchange of parameters residing in modern mathematical analysis, this novel approach offers a promising refinement for the analysis of the transmission of knowledge across space, time, and culture.

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Laure Miolo and Stefan Zieme have contributed equally to this work.

✉ Laure Miolo
laure.miolo@history.ox.ac.uk

1 Faculty of History, University of Oxford - Lincoln College, Oxford, UK

2 Humboldt-Universität zu Berlin, Berlin, Germany

List of manuscripts

A	London, British Library, Ashmole 191
CSJ	Cambridge, St John's College MS B 19
CUL	Cambridge, University Library, Ee 3.61; Cambridge, University Library, Mm.3.11
D_1	Oxford, Bodleian Library, Digby 168
D_2	Oxford, Bodleian Library, Digby 178
E_1	London, British Library, Egerton MS 847
E_2	London, British Library, Egerton MS 889
G	Cambridge, Gonville and Caius College, MS 110/179
H	London, British Library, Harley 625
BLa	London, British Library, Add MS 89442
BLr	London, British Library, Royal MS 12 G I; Nuremberg, Stadtbibliothek, Cent 34 V

1 Introduction

> By his astronomical tables drawn up on 16 March 1485, in the tower of London, where he had been placed at the command of King Richard III, Lewis of Caerleon called attention not only to his own plight but also to his abiding interest in astronomical phenomena. Yet he has failed to receive more than passing notice from recent writers, despite the several manuscripts containing the works of leading astronomers and mathematicians of both Oxford and Cambridge to which Lewis's name and notes are attached, as well as his alleged participation in the stirring events that preceded the accession of Henry VII (Tudor) to the throne of England.[1]

Those few lines are excerpted from Pearl Kibre's introduction to her article on Lewis Caerleon published in *Isis* in 1952. She provided the first modern study on Henry VII's physician, then better known for his alleged heroic involvement in a plot to overthrow Richard III, than for his writings. Not only did Kibre disentangle the confusion between Lewis Caerleon and Lewis Charlton, conveyed by John Leland (d. 1552) and then Thomas Tanner (d. 1735), but she also shed a new light on his career, works and extant manuscripts.[2] Although Kibre's work should now be updated, it remains a seminal study on Lewis. In the same article, Kibre regretted that he had not received more than passing attention from recent writers. The same conclusion can be drawn today. Despite Kibre's article, Lewis Caerleon's writings have yet to benefit from a detailed study and editions. This is not to say that no studies have been produced since 1952, but Lewis's manuscripts or works were only studied in contexts removed

[1] Pearl Kibre, 'Lewis of Caerleon, Doctor of Medicine, Astronomer, and Mathematician (d. 1494?)', *Isis* 43/2 (1952), 100–108, p. 100.

[2] Pearl Kibre provided a valuable overview of his manuscripts, and a list of Lewis Caerleon's own writings in an appendix to her article, ibid. p. 104–105; though valuable, his known manuscripts and this list should be revised. This is what we will do in a future article.

from their own scientific interest. Indeed, in his edition of Richard of Wallingford's writings John North devoted an appendix to Lewis's quotations and extensive borrowings from the *Albion* and the *Quadripartitum* of the abbot of St Albans.[3] Later, North and Hilary Carey, respectively, dedicated studies on the anonymous astrological treatise *Cum rerum motu,* the only complete copy of which is contained in Lewis's notebook (Cambridge, University Library, Ee.3.61, hereafter *CUL*).[4] Lewis's career as a Royal physician, courtier and a likely astrologer was further explored by Carey on the basis of a manuscript compiled for Henry VII (London, BL, Arundel MS 66).[5] Indeed, the picture of Lewis Caerleon as a Royal adviser, well-connected to the court and the university is also conveyed by a contemporary chronicler, such as Polydore Vergil, or early modern historians.[6] This involvement in royal politics during the troubled decades of the Wars of the Roses is also prevalent in his writings where his imprisonment and despoliation due to Richard III is used as a *topos*.[7] Thanks to Kibre's article and the aforementioned later contributions, Thomas Trout's 1887 entry in the *Dictionary of National Biography* of the 'obscure fifteenth-century scholar' was finally revised in 2004 by Keith Snedegar based on the most recent research by North and Carey.[8] More recently, Laure Miolo (one of the present article's co-authors) dedicated a study to his notebook providing new evidence about his life and manuscripts, also suggesting that some of his eclipse writings are mainly based on the works of

[3] John D. North, *Richard of Wallingford: An Edition of His Writings,* 3 vols (Oxford: Clarendon Press, 1976), III, pp. 217–220.

[4] John D. North, *Horoscopes and History* (London: The Warburg Institute, 1986); Hilary Carey, *Courting Disaster: Astrology at the English Court and University in the Later Middle Ages* (London: Macmillan, 1992).

[5] Carey (1992); Hilary Carey, 'Henry VII's Book of Astrology and the Tudor Renaissance', *Renaissance Quarterly,* 65/3 (2012), 661–710.

[6] See Polydore Vergil, *Anglica Historia*, 'Polydore Vergil, Anglica Historia (1555 version)', ed. and tr. D. F. Sutton in The Philological Museum, University of Birmingham, 2010, < https://philological.cal.bham.ac.uk/polverg/ > (accessed 1 February 2023); John Leland, *Commentarii de scriptoribus Britannicis*, (eds) Thomas Goodlad; Anthony Hall, Oxford: Sheldonian Theatre, 1709; John Bale, *Index Britanniae scriptorum: quos ex variis bibliothecis non parvo labore collegit Ioannes Baleus, cum aliis = John Bale's Index of British and other writers*, ed. by Reginald L. Poole and Mary Bateson, Oxford, 1902; Thomas Tanner, *Bibliotheca Britannico-Hibernica sive, De scriptoribus, qui in Anglia, Scotia, et Hibernia ad sæculi 17 initium floruerunt, literarum ordine juxta familiarum nomina dispositis commentarius*, London, 1748.

[7] E.g., 'Nota quod post compositionem istarum tabularum quas amiseram per exspolationem Regis Ricardi, ego existens incarceratus in turre Londonarum, composui alias tabulas eclipsium que discordant ab istis in paucis secundis, cuius causa est quia latitudo lune vera et visa differt ab ista aliquando per unum secundum et aliquando per 30 tertia tantum', Cambridge, St John's College MS B. 19, fol. 1r; London, British Library, Royal MS 12 G I, fol. 1r; London, BL, Add MS 89442; 'Require alios canones in fine proximi quaterni quos primo composui priusquam fueram incarceratus per Regem Ricardum', Cambridge, St John's College MS B. 19, fol. 6r; London, British Library, Royal MS 12 G I, fol. 6r.

[8] Thomas Trout's short entry on Lewis Caerleon was included in the note dedicated to Lewis Charleton, see: Thomas Trout, 'Charlton or Cherleton, Lewis', *Dictionary of National Biography,* 1887, 10, p. 118;), Keith Snedegar,'Caerleon, Lewis (d. in or after 1495), physician and astronomer', *Oxford Dictionary of National Biography,* from < https://www-oxforddnb-com.ezproxy-prd.bodleian.ox.ac.uk/view/10.1093/ref:odnb/9780198614128.001.0001/odnb-9780198614128-e-4324 > (accessed February 2023).

two little-known fifteenth-century astronomers from Merton College, Oxford.[9] However, in line with this renewed interest in Lewis Caerleon's manuscripts, his scientific writings deserve critical editions and more attention. This is our endeavor here with an edition and a commentary of his work on the equation of time, comprising tables and canons.[10] The first section presents the author and provides evidence that may be gleaned from various sources. The second section explores the context in which this work was composed and situates it within the other writings of Lewis Caerleon. The third section provides a comment on the sources used by the author, and more particularly the strong interest he had in the works of Simon Bredon (d. 1372). The last two sections are devoted to Lewis's table of the equation of time and the mathematical details of his method for computing it.

2 Lewis Caerleon in context

2.1 The university years

First, the name Lewis Caerleon (instead of Lewis de Caerleon) seems to have been preferred by the physician himself as testified by his autograph signatures: 'Lewys Caerlyon' or 'Lodowycus Caerlyon'.[11] Although his name points to his Welsh origins, as is clearly underlined by Polydore Vergil who designates him as 'from Wales' (*natione Wallo*) and John Leland, who describes the small Roman town of Caerleon in his entry, the first evidence about his life is found in England.[12] The earliest hint may be found in Cambridge where Lewis was a student at the Faculty of Medicine. In the fifteenth century, the Faculty of Medicine of the University of Cambridge was certainly not well endowed with students and masters, and in certain more precarious years it was even unable to admit any students. In the fifteenth century, the number of professors and students diminished to such an extent that a certain proportion of students in medicine at Cambridge decided to pursue their studies abroad on the continent, particularly in Italy, where the teaching had long been renowned.[13] This does not seem to have been the case for Lewis though, at least for years 1465–1466 when he was first admitted bachelor of medicine and in 1466 received a fine for not lecturing in this discipline.[14] However, we know nothing of his student years in Cambridge.

[9] See Laure Miolo, 'A bibliophile performing eclipse computations. Lewis Caerleon and his notebook', in *Manuscripts and Performances in Religions, Arts and Sciences,* ed. A. Brita et al., 117–186. (Berlin: De Gruyter, 2024).

[10] An edition of his eclipse tables and canons will be pursued in a future work.

[11] E.g., *CUL*, fol. 14v, 81r.

[12] 'Margareta invaletudinis causa utebatur medico nomine Ludovico natione Wallo, et quia vir gravis erat ac non minimi usus, saepe cum eo solebat libere loqui et familiariter suspirare. […]', Vergil (1555), translated by Sutton (2010); in John Leland's statement, 'Joannes, cui ab urbe Legionum, in ripis Iscae fluminis condita, nomen Cairleon vulgo inditum', Leland (1709), p. 471.

[13] Damian Riehl Leader, *A History of the University of Cambridge. Volume 1, the University to 1546* (Cambridge: Cambridge University Press, 1988), 202–210, Thomas Denman (d. 1501), and John Argentine (d. 1508) both went to the Continent to pursue their medical education.

[14] 'Item Lodowicus Carlyon quia non legit in medicinis XX'. Cambridge University Archives, Reg. I.2.32.

A plausible assumption is that he was a fellow of Clare Hall (now Clare College),[15] since two of his manuscripts were there. They are mentioned by John Leland during his visitation of Clare College in 1535:

> **[1]** '6. Tabulae Ludovici de Cairlion doctoris medicinae de eisdem rebus Londini scriptae 1482', it may be associated with the previous item described as: '5. Tabulae magistri Simonis Bredon de rebus astronomicis.'[16]
> **[2]** '14. Quadripartitum Richardi Walingford abbatis Sancti Albani de sinibus de mensuratis (sic). *Quia canones non perfecte tradunt notitiam sinus etc.*' and '15. Commentum Symonis Bredon super aliquas demonstrationes Ptolemaei Almagesti. *Nunc superest ostendere.*[17]

The first manuscript may correspond to a Clare College codex described slightly later by John Bale in his *Index Britanniae* (1548–1552). His description is much more detailed, although the contents are neither ordered nor entirely listed:

> Ludovicus Caerlion, astronomus peritus, scripsit:
> De eclipsi ac lunari: 'Modus operandi pro eclipsi lune'
> Tabulas eclipsium: 'Altitudo lune in arcu longitudo'
> Canones eclipsium 'Eclipsim solis quantitatem et dur (sic) [durationem]'
> De tabulis umbrarum: 'Circa compositionem tabularum umbrarum.'
> Atque alia plura composuit.
> Ludovicus Caerlion, Britannus, doctor in medicinis et astronomus, Londoni claruit 1482.
> Ex aula Clarensi Cantabrigie.[18]

This manuscript may probably be identified as London, BL, Add. MS 89442 (hereafter *BLa*), since no other manuscripts of Lewis's display similar associations. This volume is indeed the only extant codex to retain the tables of shadows and their canons composed by Lewis in London on the 30th of April 1482.[19] Moreover, in the description provided by Leland, the table of Simon Bredon (*tabulae magistri Simonis Bredon*) mentioned is probably the tables of chords opening this same manuscript. Therefore, Leland and Bale seem to have described the same manuscript, although with different degrees of detail.

The second volume described by Leland in 1535 provides more information as it exactly quotes the manuscript's rubrics and incipits. It should be noted that Leland's description also encompasses two items (numbers 14 and 15). It corresponds to the

15 Cf.Miolo (2024), 'A bibliophile performing eclipse computations', art. cit.

16 Peter D. Clarke, *The University and College Libraries of Cambridge* (Corpus of British Medieval Library Catalogues, 10), (London: British Library, 2002), p. 152.

17 Clarke (2002), p. 153.

18 Bale (ed. by Poole and Bateson 1902) , p. 284.

19 For the material related to shadows, see: BL, Add. MS 89442, pp. 34–35, for the tables, and p. 36 for the canons beginning: 'Circa compositionem tabularum umbrarum'. Page 38 displays an example of the computation of altitude of the shadow, this short passage concludes by providing the date of composition of the shadow tables: 'Explicit opus Lodowyci Caerlyon in medicinis doctoris, circa tabulas umbrarum, anno incarnationis imperfecto 1482°, 30 die mensis Aprilis apud Londonum'.

part of Oxford, Bodleian Library, MS Digby 178, fols. 15r–87v,[20] which was commissioned by and belonged to Lewis. This volume contains Richard of Wallingford's *Quadripartitum* (fols. 15r–38r), heavily annotated by Lewis, also including a lengthy comment of his (fols. 38r–38v) and Simon Bredon, *Commentum super Almagesti*, fols. 39r–86v. MS Digby 178 ends with Lewis's note and diagram on the distance between the Earth and the Moon (fols. 87r–87v). As we shall see, this codex and particularly Simon Bredon's treatise played a central role in the elaboration of the tables and canons for the equation of time by Lewis. Both manuscripts passed to Clare College before 1535 and were probably donated by Lewis or bequeathed by him. That Clare was Lewis's College is also reinforced by the fact that its statutes mention the study of medicine and that the *aula Clarae* hosted students in medicine.[21]

In any event, one also learns from two autograph notes written in his notebook that he donated tables to the universities of Cambridge and Oxford.[22] In Oxford, a donation of astronomical tables was made by Lewis in 1490 to 'the use and benefit of the students' of Merton College.[23] However, it is difficult to know whether this mention refers to similar benefactions made to Clare College and Merton College or additional ones. Those notes and donations certainly provide evidence about the next stages of his career. From 1481, Lewis mentions himself as a doctor of medicine, although no extant records allow us to say where he earned his degree from.[24] Despite the lack of evidence about his education between 1466 and 1481, one may assume that Lewis left Cambridge for Oxford, where a better-endowed and larger faculty of medicine existed. This may explain the donation to Merton College, but also the various astronomical tables he worked on based on the Oxford meridian. As we shall see, it is likely that Lewis maintained—directly or indirectly—relationships with Merton College and some fellows there.[25]

[20] On the whole history of this composite manuscript, see: Andrew G. Watson 'A Merton College Manuscript Reconstructed: Harley 625; Digby 178, fols 1-14, 88-115; Cotton Tiberius B. IX, fols 1-4, 225-35', *Bodleian Library Record,* 9 (1976), 207–217 [reprinted in Watson A. G (2004), Medieval Manuscripts in Post-Medieval England, (Variorum collected studies series/775), Aldershot: Ashgate, article XIII].

[21] Leader (1988), p. 205.

[22] *CUL*, fol. 147^{v}: 'Nota quod istas tabulas eclipsium et diversitatis aspectus cancellavi quia non calculavi istas tabulas ita precise sicut tabulas eclipsium quas dedi universitatibus Cantebrigie et Oxonie, insensibilis tamen est differentia et per istas tabulas satis bene et prime parte eclipsium calculari.' On fol. 151^{v}, one finds a similar note: 'Nota quod tabulas precedentes quia eas non ita precise calculavi sicut tabulas quas dedi universitatibus Cantabrigie et Oxonie tamen quasi insensibilis est differentia in calculo, experiatur quicumque velit'.

[23] '26° die mensis Octobris incathenatus erat liber in libraria continens tabulas astrologicas, secundo folio *vere puncta*, quem collegio donavit magister Lodowycus Caerlyon, doctor in medicinis et doctus astronomus, ad usum et profectum studentium in eadem. Habemus igitur magnas gracias sibi.' See H. E. Salter *Registrum annalium collegii Mertonensis 1483–1521* (Oxford: Clarendon Press, 1923), p. 139. This manuscript was chained for the common use of the students.

[24] Cf. *CUL*, fols. 14v and 107r where we can respectively read: 'Lewys Caerlyon in medicinis doctoris' and 'per calculationem Lodowyci Caerlyon in medicinis doctoris'.

[25] A discussion can be found in Miolo (2024). The tables based on the Oxford meridian are only found in *CUL*.

2.2 The 'go-between'

After 1481, Lewis Caerleon's life is more traceable, since he found his way to the court. This pathway from university to court was not uncommon and a significant number of his contemporaries ended up at court where they benefited from the patronage of magnates or the royal family, if not the king himself.[26] It seems that Lewis began his courtier career in the service of Margaret Beaufort, as a physician but also as an adviser. Although we do not know when he started to serve Henry VII's mother and her entourage, he purportedly took part in a conspiracy against Richard III. According to Polydore Virgil, he probably acted as an intermediary between Elizabeth Woodville, to whom he also served as a physician, and Margaret Beaufort, who were both working to dethrone Richard III. However, the failure of Buckingham's rebellion in October 1483 led Margaret and Elizabeth to be imprisoned in their respective houses, and it is probably at the same time that Lewis was imprisoned in the Tower of London.[27] Although no other account than his own works testifies to this imprisonment, it seems that he remained in the tower until after 16 March 1485, the date of the solar eclipse he computed and observed.[28] His release certainly occurred after the defeat of Richard III, on 22 August 1485. His support and loyalty to the Lancastrian faction are clearly visible in the number of rewards and favours he received when Henry of Richmond was crowned Henry VII. He was awarded several grants for life between 1486 and 1488, of which the apex was his appointment as one of the knights of the king's alms in August 1488.[29] He continued to serve the King and the Queen, Elizabeth of York, as a royal physician until his death after 6 May 1495, a date which appears in a short autograph note written on a slip of paper that he sent to his attorney, Master Stokes. It seems that after his release sometime around the end of the summer of 1485, Lewis started to organise the different astronomical compositions he made for that very same year. A significant part of his manuscripts is indeed dated 1485. It is in this context that Lewis composed his works on the equation of time, which we analyze in detail below.

3 Lewis and his intellectual surroundings

Although Lewis Caerleon was a physician, no medical treatise is known to have been written by him. His writings are only devoted to astronomy and seem to serve a particular purpose: eclipse computations. This particular interest in eclipses may be due to his medical practice which probably implied medical astrology. Universal judgements on the basis of eclipses were used in annual prognostications and in both medical astrology and astrometeorology.[30] According to the extant sources, his writings were

[26] On the porosity of both milieux, see Carey (1992).

[27] Polydore Vergil, *Historia Anglica*. See Kibre (1952), pp. 101–102.

[28] Cambridge, St John's College MS B. 19 and BL, Royal MS 12 G I, fol. 6v: 'Istam eclipsis Solis anno Christi imperfecto 1485, post meridiem 16 diei Martii contingentem ego observavi in turre Londoni …'.

[29] Cf. Kibre (1952), 102–103.

[30] For example, the effect of the solar eclipse of 16 March 1485 had been discussed from a medical perspective by Diego de Torres (ca. 1480–after 1487), who held the chair of astrology at the University

concentrated within a short period of time between 1481 and 1485. Several extant manuscripts copied and commissioned by Lewis allow us to reconstruct the chronology of his astronomical compositions. We will highlight three stages.

3.1 Lewis's astronomical production: the early stage 1481–1482

The first evidence of his scientific activity may be found in his notebook (*CUL*) where he gathered several of his sources but also kept a record of some of his compositions. This corresponds to the early stages of his *Opus eclipsium,* including drafts and early versions of his writings. Although Pearl Kibre and other scholars understandably assumed that this manuscript contained the first version of Lewis's eclipse and parallax tables, one of the authors of this article (Laure Miolo) recently showed that those tables, and probably the canons appended to them, were authored by a Merton College fellow named John Curteys (d. 1448/1449).[31] Those tables based on the Oxford meridian certainly laid the foundations for Lewis's work on eclipses, since he expanded them and based his own tables on them. He employed for the first time his revision of John Curteys' tables in the computation of the solar eclipse of 28 May 1481 based on the Oxford meridian. This eclipse was computed with four different sets of tables: the Toledan Tables and John of Lignères's Tables of 1322 in the first instance,[32] and then, from the true conjunction (found with the Alfonsine Tables), John Curteys's tables called *nove tabule.*[33] A last set of tables is used by Lewis who named them *nove tabule expanse,* corresponding to the revision he made from the *nove tabule.*[34] It should be noted that John Curteys's tables based on the Oxford meridian are derived from the parameters of Richard of Wallingford's *Albion,*[35] as is the revision by Lewis, who expanded his tables 'to the individual minutes, rejecting all fractions up to the minute, both in time and in motion'.[36] Those expanded tables are not found in the notebook, but may well coincide with the tables 'expanded to the individual minutes' dated to 1482 and found in manuscripts that Lewis commissioned and supervised after his release in 1485.[37] In any case, even if the *nove tabule expanse* used for the computation of the solar eclipse of 1481 correspond to an earlier state based on the Oxford meridian, the 1482 tables clearly derive from it.

Footnote 30 continued
of Salamanca: Marcelino V. Amasuno, *Un texto médico-astrológico del siglo XV: 'Eclipse del sol' del licenciado Diego de Torres* (Cuadernos de historia de la medicina española: Monografias, 21), (Salamanca: Universidad de Salamanca, 1972).

31 Cf. Miolo (2024). A short entry on John Curteys may be found in Alfred B. Emden, *A Biographical Register of the University of Oxford to A.D. 1500* (Oxford: Clarendon Press, 1959–1974), p. 530. John Curtey's tables are contained in *CUL*, fols. 147v-151v and the canons fols. 152v-153v.

32 *CUL*, fols. 12v–13v; for the edition of the Toledan Tables, see Pedersen (2002), for John of Lignères's tables see Chabás and Saby (2022).

33 *CUL*, fols. 13v-14va.

34 *CUL*, fol. 14vb.

35 Cf. Miolo (2024).

36 *CUL*, fols. 14vb: 'Calculatio eiusdem per tabulas novas expansas ad singula minuta abiciendo omnes fractiones usque ad minuta, tam in tempore quam in motu'.

37 The 'twin' manuscripts, Cambridge, St John's College MS B 19 and BL, Royal MS 12 G I, and *BLa* contain the set of eclipse tables composed in 1482.

The same computation retains two other methods to calculate the solar eclipse, an arithmetical and a geometrical procedure. The latter one is entitled *Demonstratio geometrica* and is based on mean values and on the geometrical model explained in the first part of Richard of Wallingford's *Albion.*[38] This seems to be a first attempt to apply a method that Lewis fully theorised later in a canon entitled, *De modo calculandi eclipses geometrice sine tabulis*.[39] The computation of the 1481 solar eclipse clearly displays the genesis of Lewis's astronomical works, and how he carefully applied the tables he derived and method he developed for this calculation.

Amongst the earliest astronomical composition of the physician there are two tables, one devoted to the difference between the mean velocities of the two luminaries in hours of time at mean syzygy, and the other displaying the difference of velocities at true syzygies. They are accompanied by short canons.[40] That both tables are the starting point of a larger and expanded work becomes clear with *BLa*, which retains a whole set of tables of syzygies entitled, 'Tabula revolutionis coniunctionum et oppositionum solis et lune cum motibus' (*BLa*, pp. 72–117) with their canons (*BLa*, pp. 117–118). This more extensive set was probably developed in 1482, given the use of an *exemplum operationis* (an example of calculation) based on the first conjunction of this very same year.[41]

Lewis's notebook displays some of the early stages of his astronomical compositions that we may date to around 1481 based on the eclipse computation. It should be underlined that those different attempts, especially the eclipse and parallax tables, are all based on the Oxford latitude. This may be due to his main source, John Curteys, whose tables are based on this same latitude, but it is also likely that at that time, Lewis was himself in Oxford where he had access to Merton College manuscripts as we shall see shortly. If we summarize the information provided by *CUL*, except several notes and computational examples, Lewis surely authored: (1) a set of eclipse tables that are not extant, called *nove tabule expanse,* perhaps a first version of the 1482 tables; (2) an attempt at a 'geometrical' method of eclipse computation; (3) a table of mean and true syzygies; (4) the computation of the solar eclipse of 28 May 1481.

38 North (1976), I., pp. 283–294

39 This canon is displayed in Cambridge, St John's College MS B 19, fols. 7v–8v; and BL, Royal MS 12 G I, fols. 7v-8v; *BLa*, pp. 124–125, it begins with: 'Quicumque voluerit quantitatem et durationem eclipsis lunaris geometrice perscrutari', and ends 'Nota tamen quod linea *m.k.* est, nota quia est residuum semidiametri umbre subtracto inde prius semidiametro lune ergo eius quadratum erit notum. Explicit opus magistri Lodowyci Caerlyon in eclipsibus lune et solis, excepto quod in eclipsi solis accipies semidiametrum solis in vice semidiametri umbre.'

40 *CUL*, fols. 155r-156r for the tables, and fols. 154vb and 156r for the short canons.

41 *BLa*, pp. 117: 'Volo ergo invenire primam mediam coniunctionem Ianuarii anno domini imperfecto 1482, ideo reducam annos Christi perfectos 1481 ad quarta, tertia, secunda et prima…'. A shortened version of the table for finding true syzygy is also included in BL, Arundel MS 66, fols. 258r–v. This manuscript was commissioned in the entourage of Henry VII and completed in 1490. This is further evidence of the potential association of Lewis with this manuscript. A different shortened version of the table is found in a late fourteenth- early fifteenth-century English manuscript, Cambridge, UL, Mm.3.11, 60r-61v. We are indebted to Rich Kremer for pointing out these two manuscript witnesses to us.

3.2 The development of an astronomical programme 1482–1483

Three other manuscripts help to provide a better picture of Lewis's compositions. They were all commissioned and supervised by him as can be seen from the autograph notes *corrigitur* or *relegitur* written in a pale ink in the lower margins of the volumes. All of them belong to a publication process carefully planned by Lewis after 1485, since they all display works dated to that year, including the computation of the solar eclipse of March 1485, and refer to his imprisonment by Richard III. That they all proceed from the same publishing endeavour seems clear, since only Lewis's works are contained in those manuscripts copied by professional scribes.

Two of them are what might be called twin manuscripts. Cambridge, St John's College MS B 19 (hereafter *CSJ*) and BL, Royal MS 12 G I (*BLr*) are indeed both copied on sixteen folios of parchment, have the same dimensions and contain the same texts and tables ordered in exactly the same way.[42] The only difference is that they were both copied by two different scribes. No other evidence allows us to say for whom these volumes were intended, although *CSJ* displays a clear chain mark on the upper cover indicating that the manuscript entered in an institution. However, the volume does not correspond to the records related to Clare College or Merton College, and may well coincide with the donations to the Universities of Oxford and Cambridge mentioned by Lewis in his notebook. Despite the lack of evidence regarding the provenance of both codices, it seems that the physician's purpose was to provide two different people or institutions with his eclipse writings. Indeed, the contents of both manuscripts are only related to eclipses, which contrasts with the third volume *BLa*, which contains a larger and more diverse number of works produced by Lewis. *BLa* is a large manuscript consisting of 128 pages of parchment, copied by the same scribe as *BLr* and may be considered Lewis's *Opera omnia.* The large chain mark on the contemporary blind-tooled upper cover confirms that the manuscript belonged to an institution, which seems to be Clare College.[43] As *BLa* is Lewis Caerleon's *Opera omnia,* it retains similar works as in *CSJ* and *BLr* in addition to other writings which are not displayed in the twin manuscripts.

Most of the eclipse work was produced by the royal physician in 1482. A mention predating the elaboration of the eclipse and parallax tables may be found in his notebook in front of parallax tables said to be excerpted from John Somer's book. In some way, this short note describes a part of Lewis Caerleon's programme:

[42] *CSJ* came from the collection of William Crashaw (d. 1625/1626) and was then purchased in 1615 by the Thomas, Earl of Southampton, who donated the manuscript with others to the St John's College in 1635 (cf. plate on the inside upper cover and mention Th. C. S. on the second upper flyleaf); *BLr* was purchased from a certain Doctor Laidon or Laidun, priest of St Faith in the Church of St Paul in London, who might be Richard Laiton or Layton (d. 1544), by Nicolas Frazer on 15 June 1535, fol. 15^{v}: 'Ego Nicolaus Frazerus emi hunc librum ab doctore Laidun pastori Sancte Fide in divino (sic) Pauli ecclesia Londinensis anno 1535 die 25 Iunii'. *BLr* then passed to the private library of John Lumley (d. 1609), which was acquired with the whole Lumley's collection by the Prince of Wales around 1603 to finally end up in the Royal Library.

[43] The only evidence about the early provenance of the manuscript is provided by Leland's visitation and Bale's *Index*. *BLa* was still at Clare College when Bale composed his *Index* (1548–1552). Some decades later the manuscript entered under unknown circumstances in Henry Spelman's collection, *BLa,* p. 1: 'Henrici Spelmanni liber emptus 11 April 1606'. The manuscript passed through the hands of various antiquarians before entering in the library of the Earls of Macclesfield through Thomas Parker (d. 1733), 1st Earl of Macclesfield.

> With God's favour, I propose to build other new parallax tables based on the meridian of the University of Cambridge and new eclipse tables with all tables for the same purpose.[44]

As was the case with John Curteys's eclipse tables, the revised and expanded tables made by Lewis in 1482 are based on the parameters of the *Albion,* more particularly from Book I, chapters 18, 19 and 21 containing the diameter values needed for computing a part of these tables.[45] As stated in the short note, the new parallax tables elaborated by Lewis are indeed based on the latitude of Cambridge as stated in their headings.[46] This information is also repeated in both eclipse canons found in the twin manuscripts.[47] Although the parallax tables are designed for Cambridge, the heading of the solar eclipse tables provide valuable evidence about the context of composition. They were composed in London, when Lewis was physician of Margaret Beaufort.[48] Those tables provide entries for lunar/solar eclipses digits, the difference of digits between the apogee and perigee, the *minuta casus* and *dimidium more*. The eclipse tables of 1482 are accompanied with two sets of canons elaborated at different times. The twin manuscripts are the only witnesses displaying both canons and a mention at the end of one of the texts provides a better understanding of the context. It reads: 'Seek at the end of the next quire for the other canons that I composed before I was incarcerated by King Richard'.[49] A first version of the canons was, therefore, composed in 1482, whereas another text was composed after 1485.[50]

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44 *CUL*, fol. 152^{r}: 'Alias, tunc favente Deo, novas tabulas diversitatis aspectus ad meridiem Universitatis Cantebrigie propono construere et novas tabulas eclipsium cum omnibus tabulis easdem continentibus etc.'

45 The eclipse tables with the headings are found in *BLa* (pp. 65–71); *BLr* and *CSJ*, fols 1^{r}–3^{v}. E.g., *CSJ*, fol. 1^{r}: 'Hic incipit tabula eclipsis Lunaris secundum dyametros Ricardi abbatis de Sancto Albano, libro suo primo de compositione Albionis conclusione 18, 19 et 21, ad longitudinem longiorem cum differentia punctorum et minutorum casus et more, ad longitudinem propriorem noviter facta et expansa ad singula minuta argumenti latitudinis Lune per me Lodowycum, anno Christi 1482 et huic tabule finaliter adhereo ut in principio huius operis premisi'.

46 These tables are contained in *BLa,* p. 59, *BLr* and *CSJ,* fol. 5r: 'Tabula diversitatis aspectus in longitudine et latitudine veri polus elevatur 52 gradus 20 minuta. Supposita maxima solis declinatione 23 gradus, 28 minuta 17 secunda et si declinatio esset 23 gradus 33 secunda, non variaret nisi in paucis secundis. Et scias quod iste diversitates aspectus hic posite sunt archus et non corde. Lewys'.

47 *BLr, CSJ,* fol. 6r, *BLa*, p. 70: 'Intra in tabulam diversitatis aspectus factam pro latitudine 52 gradus et 20 minuta quod suppono latitudinem Cantebrigie quam noviter composui'. The other canon is only found in *BLr,* fols. 15r-v and *CSJ,* fols. 14v–15r, the similar passage reads: 'Intra in tabulam diversitatis aspectus factam pro latitudine Cantebrigie et dividitur in 2 tabulas, quarum una est de diversitate aspectus in longitudine, et altera de diversitate aspectus in latitudine'.

48 *CSJ* and *BLr*, fol. 3r: 'Hic incipit tabula eclipsis solis secundum diametros Ricardi Abbatis de Sancto Albano ad longitudinem longiorem cum differentia punctorum et minutorum casus ad longitudinem propriorem Lune. Sed sol supponitur esse semper in sua longitudine medie in compositione istius tabule per me Lodowycum anno Christi imperfecto 1482 apud Londonum'.

49 *BLr* and *CSJ,* fol. 6r: 'Require alios canones in fine proximi quaterni quos primo composui priusquam fueram incarceratus per Regem Ricardum'.

50 It should be noted that the first version of the canons (*BLr,* fols. 15r-v and *CSJ,* fols. 14v-15r) is largely inspired by the canons contained in the notebook which were composed for John Curteys's tables; only the Oxford mention allows us to differentiate both versions as the 1482 version substitutes Oxford for Cambridge. The version of 1482 begins with: 'Modum operandi pro eclipsi lune per tabulas novas. Intra in tabulam eclipsis lunaris cum argumento latitudinis […] Canones eclipsium solis secundum easdem tabulas. Pro quo primitus ista sunt requirenda …'; the second version is found in *BLr* and *CSJ,* fols. 5v-6r, *BLa,*

Amongst the eclipse works dated to around 1482 and contained in the three manuscripts there are canons to parallax tables, the method to compute an eclipse geometrically without tables and the table of concordance between the radii values excerpted from Richard of Wallingford's *Albion* and al-Battānī's *De scientia astrorum* already displayed in the notebook. This work was pursued with new interpolation tables made by Lewis in 1483.[51] Those sets of eclipse and parallax tables were finally used to compute the eclipse of 16 March 1485. Along with the detailed computation, the twin manuscripts also include the comparison between the computation and the observation made by Lewis, although it is absent from *BLa*.

CSJ and *BLr* were conceived by Lewis as an *opus eclipsium,* an instrument for predicting eclipses. He certainly selected the material to be included in both manuscripts. The purpose of *BLa* is slightly different, since its likely aim was to assume the status of *opera omnia.* In that context, *BLa* retains more eclipse material, such as an introduction to the complete eclipse work as well as a unique set of eclipse tables based on al-Battānī's values composed in 1482 (*BLa,* pp. 61–64). The introduction explains why Lewis has chosen to keep only the tables based on the values provided by the *Albion* instead of the sets of tables deriving from al-Battānī's *De scientia astrorum.* He tested the accuracy of both sets of tables in predicting the solar eclipse of 17 May 1482, and ultimately endorsed the *Albion*'s values.[52] As was the case with the eclipse of 28 May 1481, Lewis tested his own tables for the 1482 eclipse. Hence, the presence of this set in the twin manuscripts.[53]

In this eclipse work, the equation of time was necessary to calculate eclipses. It is mentioned in the solar eclipse canons written by Lewis in 1482 and 1485 as part of the requirements for the calculation:

> [Canons of 1482] Canones eclipsium solis secundum easdem tabulas. Pro quo primitus ista sunt requirenda et memorie commendanda, scilicet tempus vere coniunctionis luminarium, diebus equatis, verus locus luminarium, argumentum verum lune, superation lune in una hora [...][54]
> [Canons of 1485] Circa calculationem eclipsis solis ista sunt primitus requirenda et memorie commendanda, scilicet, tempus vere coniunctionius luminarium,

Footnote 50 continued
pp. 70–71, and was composed after 1485, it begins: 'Postquam novas tabulas eclipsium composuerim cum singulis tabulis ad easdem pertinentibus, convenit ut modus operandi per easdem plane declarem [...] Circa calculationem eclipsis solis ista sunt primitus requirenda et memorie comendanda, scilicet, tempus vere coniunctionis luminarium diebus equatis'.

51 *CSJ* and *BLr*, fol. 4^r: 'Tabula minutorum proportionalium seu tabula proportionis vel affinitatis seu portiones longitudinum ad eclipses per me Lodowycum noviter facta anno Christi 1483'.

52 *BLa,* p. 39: 'Ego tunc unam eclipsim solis observavi, anno imperfecto 1482, post meridiem 17 diei Maii quo ad initium eclipsis 5 horis 54 minuta et finis eiusdem post horam 7am 42 minutis, quod mihi ad sensum et aspectum visum est concordare cum sententiis Ricardi Abbatis. Et ideo illius magis adherere propono, nisi in posteris per observationes contrarium probavero ad sensum in aspectu, et sic faciant qui me secuntur brevis canon componendi tabulas eclipsium Lewys.' A horoscope chart of the eclipse and some computed values are found in *CUL*, fol. 1r.

53 We can read these words in the heading of the lunar eclipse tables: 'et huic tabule finaliter adhereo ut in principio huius operis premisi' (*CSJ, BLr,* fol. 1r and *BLa*, p. 61). One cannot exclude the possibility that the twin manuscripts were commissioned slightly after *BLa.*

54 *BLr,* fol. 15r and *CSJ,* fol. 14v.

diebus equatis gradus ascendentis pro eodem tempore verus locus luminarium, argumentum verum lune superatio lune in una hora [...][55]

The equation of time is also used in his own eclipse computations. For the solar eclipse of 28 May 1481, Lewis computed the correction according to the equation of time on the basis of two different sets of tables, the Toledan Tables and John of Lignères Tables of 1322:

Tempus vere coniunctionis diebus non equatis post meridiem prescriptis 3 hore, 51 minuta, 45 secunda, 31 tertia
Equatio dierum secundum magistrum Johannem de Lineriis, 19 minuta, 18 secunda, 16 tertia, 30 quarta
Equatio dierum secundum Azarchelem 20 minuta, 21 secunda, 32 tertia.[56]

Similarly, a correction by the equation of time is given in his calculation of the solar eclipse of 16 March 1485: 9 min and 36 s.[57] To correct the time of true syzygy by the equation of time was, therefore, an important step in eclipse prediction. This may explain why in 1485 Lewis decided to construct his own table.

3.3 The *Opera omnia* and its contents

If Lewis Caerleon's main focus was on eclipse prediction, he gathered a large amount of information and materials in order to derive new eclipse and parallax tables. *BLa* is the only surviving example of these works, although some early drafts can be identified in the notebook. The manuscript is divided into different sections covering spherical astronomy, prediction of eclipses, arithmetic/trigonometry, and the equation of time.

The trigonometric section begins with a table of sines and chords ascribed to Simon Bredon (d. 1372) and revised by Lewis Caerleon, followed by canons composed by the royal physician.[58] The revision offered by Lewis consists in expanding the table to every minute of arc, which is said to be more precise than al-Battānī's table. *BLa* is the only witness to this table, although Bale saw a manuscript in Clare College which contained a similar table along with related texts.[59] The manuscript is described by Bale as follows:

Simon Bredon, Wichecombensis, astrorum magister, scripsit:

55 *BLr* and *CSJ,* fol. 5v, *BLa,* p. 70.

56 *CUL*, fol. 12^{v}:

57 *BLa,* p. 71 and *CJS, BLr,* fol. 16v: 'Equatio dierum 9 minuta 36 secunda'; given the longitude of the true sun of 5;24,30° at true syzygy, this value for the equation of time exactly corresponds to the value derived from Giovanni Bianchini's modern equation of time, contained in his *Tabula primi mobilis B*, by linear interpolation.

58 *BLa,* pp. 1–30; *BLa,* p. 1: 'Tabula cordarum mediatarum Magistri Symonis Bredon expansa ad singula minuta per me Lodowycum et est precisior quam tabula Albategni quia caculatur pro singulis 15 minutis usque ad octavam. Sed hic non posui nisi quarta verificata pro singulis 15 minutis'. The canons are on pp. 31–33.

59 Bale (ed. by Poole and Bateson 1902) , p. 410; the information is then repeated by Tanner (1748), p. 122: 'Scripsisse etiam fertur *Tabulas chordarum:* Arcus sinus rectus, sinus versus; *Calculationes chordarum,* 'Ad allevationem laboris calculantium'.

[1] Commentum super aliquas demonstrationes Almagesti: *Assensiones equalium portionum zodiaci.*
[2] Tabulas cordarum: *Arcus, sinus rectus, sinus versus.*
[3] Calculationes cordarum: *Ad alleviationem laboris calculanti.*
Claruit A. D. 1386.
Ex aula Clarensi Cantabrigie.[60]

The first item corresponds to Simon Bredon's *Commentum super Almagesti,* Book I, and the incipit given is from Book I, Chapter 12.[61] This was followed by the table of chords and a short text which may correspond to a canon describing the method of computing chords. However, none of the other witnesses to Simon's commentary agree with this manuscript which may have been lost or dispersed at some point. However, the presence of this volume in Clare College may point to Lewis Caerleon's main source for his adaptation of Simon's table.

The section devoted to the sines and chords is followed by shadow tables and their canons. The canons mainly refer to John of Lignères's spherical astronomy canons *Cuiuslibet arcus,*[62] and include a short text explaining how to make an instrument using the back of the astrolabe's alidade to measure angles.[63] This section also shows a justification of his shadow tables, which were used to calculate the maximum declination of the Sun and to make astronomical observations. This portion on arcs and sines ends with a table of square roots showing an example of an altitude calculation based on Lewis's shadow table. Interestingly, the *explicit* gives a precise date for the preparation of this section. It was indeed completed in London on 30 April 1482.[64]

60 Bale (ed. by Poole and Bateson 1902), p. 410.

61 Cf. the first two books of Simon Bredon's *Commentum super Almagesti* are edited in Henry Zepeda, *The Medieval Latin Transmission of the Menelaus Theorem* (unpublished doctoral thesis, University of Oklahoma at Norman, 2013), pp. 282–230 (for the analysis of the text) and pp. 637–686 (for the edition of Books I–II). For a discussion on this commentary, see H. Zepeda, *The First Latin Treatise on Ptolemy's Astronomy: The Almagesti minor (c. 1200)* (Turnhout: Brepols, 2018), pp. 95–98; David Juste, 'Simon Bredon, Commentum super Almagesti' (update: 16.06.2022), *Ptolemaeus Arabus et Latinu*s < http://ptolemaeus.badw.de/work/7 > (consulted 10 July 2023).

62 Marie-Madeleine Saby, *Les canons de Jean de Lignères sur les tables astronomiques de 1321,* 3 vols (unpublished thesis, École nationale des chartes 1988), I, pp. 1–71; Lewis owned a copy of those canons in *CUL*, fols. 86v-96r; he refers explicitly to John of Lignères in the canons, *BLa,* p. 36a: 'Si vero velis eam artificialis corrigere age secundum canones magistri Johannes de Lineriis'.

63 *BLa,* p. 36b. 'Istas tabulas feci propter rectangulum ut accipere maximam solis declinationem et propter alias observationes faciendas circa principia scire astronomice. Sed nota bene quod si velis operari per rectum angulum certius est facere quadratum cum regula seu alidada quadratum habetur in dorso astrolabii [...] Et scias quod non patet ingeniari certius instrumentum ad observationes quam tale quadratum taliter situatum ut productum est. Si circumscribatur area plana circularis equidistans orizonti cum linea meridiana et azimuth, fora autem istius rectanguli quadrilateri erit hec ut patet in figura subsequente.' The instrument (a *quadratum geometricum* or *gnomo geometricus*) made by Lewis is drawn in front of the text. It consists in two right-angled triangles joined to form a quadrilateral with one leg and the diagonal marked by another ruler. Two *pendicula* (small strings) hang opposite each other to measure angles. Peurbach also elaborated a *quadratum geometricum,* see Georg von Peurbach, *Scripta clarissimi mathematici M. Ioannis Regiomontani, de Torqueto, astrolabio armillari, regula magna Ptolemaica, baculoque astronomico, & obseruationibus cometarum,* ed. Johann Schöner (Nuremberg, 1544), fols. 61–64. We are grateful to Rich Kremer for this reference.

64 *BLa,* p. 38: 'Explicit opus Lodowyci Caerlyon in medicinis doctoris circa tabulas umbrarum anno incarnationis imperfecto 1482, 30 die mensis Aprilis apud Londonie'.

As in the other parts of the manuscript, Lewis includes all the material needed to calculate other pieces. In particular, the tables attributed to Simon Bredon were used by Lewis to prepare his shadow tables. This *explicit* also clearly shows that the author has thought of the thematic divisions as independent *opera,* which he put together as a whole *opera omnia*.

The *Opus eclipsium* follows directly as a separate section, introduced by a one-page statement which has only survived in *BLa*. This introductory text provides the year of elaboration, 1482, and the method used by Lewis to produce the eclipse tables. In particular, it highlights how he tested his two sets of tables in the context of the eclipse computation of 17 May 1482.[65] Interestingly, Lewis not only provides both sets of eclipse tables, parallax tables and their canons, but also includes all the material used in the preparation of this work. Thus, after the introduction, two pages are devoted to the compilation of eclipse tables based on al-Battānī's values.[66] Diameters and radii and related material taken from the Arabic astronomer's work are carefully listed, followed by tabular calculations based on them.[67] The tables are said to have been made in 1482.[68] A similar compilation of radii and diameters and calculation materials is found right after, but this time based on Richard of Wallingford's *Albion.*[69] In contrast to the al-Battānī section, a short text introduces the method used by Lewis to calculate the tables and justifies his final decision to retain Richard of Wallingford's values rather than those of al-Battānī.[70] According to this explanation, Lewis did not have a direct access to the Arabic astronomer's treatise, but rather to the *Albion* and a compilation taken from the book of a fellow of Merton College, Walter Hertt (d. 1484).[71] Instead of following the pages dedicated to the table calculations, the two sets of eclipse tables conclude the *Opus eclipsium.* Rather, the material that immediately follows is devoted to other steps of the calculation of eclipses. The table of proportion for proceeding to the interpolation between two eclipse tables is, therefore, necessary to compute the time between the beginning and the middle of an eclipse, the number

[65] *BLa,* p. 39: 'Hic incipit opus eclipsium per me Lodowycum anno Christi imperfecto 1482 qui me dirigat sua gratia per semitam veritatem.'

[66] *BLa*, pp. 40–41; in addition to the diameters and radii values, four tables summarize the computations made by Lewis (*BLa,* pp. 40–41), and four others show the final results (*BLa,* p. 41).

[67] The values are excerpted from chapters 30, 43 and 44 of al-Battānī's *De scientia astrorum,* see al-Battānī (Albategni), *al-Battānī sive Albatenii opus astronomicum. Ad fidem codicis Escurialensis arabice editum. Latine versum, adnotationibus instructum,* ed. Carlo Alfonso Nallino, 3 vols (Milan: Ulrico Hoepli, 1899–1907), I, pp. 50–63, 96–113.

[68] *BLa,* p. 41: 'Tabule eclipsium in suo ordine constitute et per me Lodowycum secundum semidiametros Albategni noviter facte anno Christi 1482 quarum calculatio hic per ordinem preponitur.'.

[69] *BLa,* pp. 41–43, the section is introduced by a table of diameters and radii entitled: 'Sequitur quantitas diametrorum solis et lune et umbre secundum Ricardum de Sancto Albano Abbate'.

[70] This text is displayed on p. 42; it begins with 'Sequitur calculatio tabularum eclipsium Solis et Lune secundum semidiametros Solis, Lune et Umbre a Ricardo Wallinforthe abbate de Sancto Albano positos libro suo primo de compositione Albionis conclusione 18, 19, et 21 sub hac serie verborum conclusione 18' and ends with a justification of Lewis's choice: 'Iste Ricardus allegat commentatorem *Almagesti* et capitulum 84 (sic) [44] Albategni perfecti quos non habemus summam vero libri Albategni in libris quos vidi in precedente opere allegavi. Ists precedentes conclusiones Ricardi hic induxi, quia suius sentenciis magis considero et finaliter adherere propono'.

[71] This short work entitled *De arte componendi tabulas eclipsium* lists diameters and radii taken from the *Albion* and comparing them with al-Battānī's, *CUL*, fol. 142r. Cf. Miolo (2024).

of digits of the eclipse and the minutes of immersion. It is this type of table, derived from *Almagest* VI, 8, that Lewis developed.[72] Following his usual method, a canon first explains the procedure for calculating the table, giving the details of the geometric model, including two diagrams.[73] Then, the table of proportions extended by Lewis to the single degree is copied just after a table allowing the calculation of the argument with which to enter the table, the lunar anomaly.[74]

Lewis devotes a considerable part of the manuscript to the computation of the parallax tables.[75] The different stages of the elaboration of the tables are thoroughly recorded by the author, notably some components related to the *primum mobile* necessary to derive those tables. This subdivision of the manuscript is introduced by a brief canon explaining the principles and prerequisite values of the parallax table, which in turn acts as an introduction to the tables of right and oblique ascension that Lewis composed.[76] This also leads Lewis to record and compare a list of different values for the obliquity of the ecliptic excerpted from the *Almagest,* al-Battānī, Jābir ibn Aflaḥ, Simon Bredon and John Hobroke.[77] Interestingly the tables are all based on the Cambridge latitude whereas some values, such as the solar parallax in altitude, are based on London.[78] Similarly, the *exemplum calculationis* just before the closing of the parallax section takes the latitude 52;20° of Cambridge.[79]

The chapter on eclipses contained in *BLa* ends with a copy of both sets of eclipse tables made in 1482 (respectively, based on al-Battānī and Richard of Wallingford) followed by the eclipse canons composed in 1485 and the computation of the solar eclipse of 16 March 1485 called *Exemplum calculandi eclipsis Solis per novas tabulas que contingit anno Domini imperfecto 1485 post meridiem 16 diei Martii.*[80] This last piece clearly shows that Lewis was keen to test the tables he had compiled as well as

[72] Gerald J. Toomer, 'A Survey of the Toledan tables', *Osiris* 15 (1968), p. 5–174, table no. 80, p. 117; Fritz S. Pedersen, *The Toledan Tables. A review of the manuscripts and the textual versions with an edition,* 4 vols*,* (Copenhague: Kongelige Danske Videnskabernes Selskab, 2002), pp. 1440–1446, see particularly pp. 1444–1446. On *Almagest* VI, 8, see Gerald J. Toomer, *Ptolemy's Almagest* (London: Duckworth, 1984), p. 308.

[73] *BLa,* pp. 44–45.

[74] *BLa,* p. 45–46. The second table is the table of proportion entitled: 'Eadem tabula minutorum proportionalium que a plerisque vocatur tabula proportionalis vel affinitatis seu portiones longitudinum ad eclipses a me Lodowyco noviter facta secundum demonstrationes precedentes hic subscribitur expansa per me ad singulos gradus argumenti veri Lune'.

[75] *BLa,* pp. 46–60, the canon begins: 'Tabulam diversitatis aspectus lune in longitudine et latitudine ad opus eclipsium Solis compositurus in mente notavi quam diligentius potui omnia ea que ad hoc et requiruntur …'.

[76] The tables of right and oblique ascensions are copied on pp. 53–55, the parallax tables are on pp. 56–60. The canons of the parallax tables are situated on pp. 51–52.

[77] *BLa,* pp. 46–49. Lewis seems to have been quite interested in Simon Bredon's derivation of the solar declination, see *infra.*

[78] *BLa,* p. 46: 'Diversitas aspectus Solis in circulo altitudinis apud London in capite Cancri secundum Albategni 1 minuta, 2 secunda, secundum Ptholomeum 1 minuta, 20 secunda', for the tables, see e.g., *BLa,* p. 53, where the right ascension table is based on the altitude 52;20° corresponding to Cambridge.

[79] This example is based on al-Battānī, Chapter 39 (Nallino, *al-Battānī*, I, p. 76–84), *BLa,* p. 59: 'Exemplum calculationis secundum processum Albategni capitulo 39, pro latitudine 52.20, pro hora tertia post meridiem Luna et Sole in principio Libre 6, 0 gradus, 0 minuta, 0 secunda'.

[80] *BLa,* p. 71.

his method of calculating eclipses. It is probably a way of demonstrating the accuracy and thus the legitimacy of his own work.

The last part of the manuscript displays a long set of tables devoted to the difference between the mean velocities of the two luminaries probably made, according to their canons, in 1482.[81] The equation of time material is situated just after this canon and is followed by a different range of materials, such as a table of multiplication and division for sexagesimal numbers and canons developing Lewis's geometrical method to compute the quantity (the magnitude of the eclipse, that is the part of the disk which is obscured) and duration of an eclipse.[82] The volume ends with canons for calculating parallax.[83]

4 Equation of time

There are finally only a handful of works that Lewis produced in 1485 in comparison with the *annus mirabilis* of 1482. This could of course be explained by the troubled context repeatedly mentioned by Lewis. Amongst the writings produced in 1485, there are other eclipse tables mentioned by the author, but which do not seem to have survived,[84] eclipse canons, the computation of the solar eclipse of March 1485 and the equation of time. The tables of the equation of time and their canons are only displayed in *BLa.* Like other astronomical works preserved in the volume, they serve the main purpose of the author, the calculation of eclipses.

4.1 The canon

Canons and tables related to the equation of time are contained on pages 118–121. Two tables are displayed alongside the canon. The final table may be found on page 121and displays values for the equation of time for each individual degree of the twelve zodiac signs in degrees and minutes, and, likewise, in minutes and seconds of hours. It is preceded by a longer table with intermediate results which was used by Lewis to compute the final table of the equation of time. As he previously did for other of his works, he retained the preparatory material used for his calculations. The canon (*BLa,* p. 118) associated with the table of the equation of time is a short text of around 1,130 words describing the different steps used to calculate the table. It was written

[81] The values are displayed in degrees (*BLa*, pp. 71–76), minutes and seconds (*BLa*, pp. 77–116). They are supplemented by a table of the mean motion of the sun and the moon, the mean argument of the moon at mean conjunction and the mean motion of the head of the dragon (the lunar node) (*BLa*, p. 71). The canons are situated on pp. 117–118.

[82] For the table of multiplication and division and its canon, see: *BLa,* pp. 121–123; for the 'geometric' canons, see *BLa,* pp. 123–126.

[83] *BLa,* pp. 126–128, it is followed by a parallax table based on al-Battānī, chapter 39, entitled: 'Diversitas aspectus tam Solis quam Lune in circulo altitudinis secundum Albategni'.

[84] We can find a reference to those missing tables as follows: 'Nota quod post compositionem istarum tabularum quas amiseram per exspolationem Regis Ricardi, ego existens incarceratus in turre Londoniarum, composui alias tabulas eclipsium que discordant ab istis in paucis secundis, cuius causa est quia latitudo lune vera et visa differt ab ista aliquando per unum secundum et aliquando per 30 tertia tantum', *CSJ*, fol. 1r; *BLr*, fol 1r; *BLa,* p. 65.

immediately after the 1482 canon dedicated to the computation of mean syzygies. This sequence of texts coincides perfectly with the end of this canon which mentions the equation of time:

> […] et super tempus resultans, adde equationem dierum cum vero loco Solis inventam in tabula nova equationis dierum.[85]

Lewis clearly states that his equation of time is a new work and distinguishes it from the 1482 mean syzygies canon. This appears on the same page, with a note added by the scribe in the margin of the canon including a *signe-de-renvoi* ⊙ and reading *Novum opus,* confirming at the same time, that this was written after 1482. That Lewis's equation of time material dates to 1485 is explicitly mentioned in the respective headings of the tables:

> p. 119: Compositio tabule equationis dierum per me Lodowycum anno Christi 1485 supponendo augem Solis in primo gradu Cancri perfecto cuius compositionis canones proponitur in proximo folio ad signum tale ⊙ aux verum Solis in Cancro 1 gradus.[86]
> p. 121: Tabula equationis dierum in motu et in tempore per me Lodowycum Caerlyon noviter facta anno Domini 1485 in turre Londoniarum.[87]

According to the latter heading of the final table, Lewis had composed his equation of time table in the Tower of London. Whether he was still imprisoned in the Tower or not, the table was composed in London in 1485. Moreover, the title of the table with intermediate results (p. 119) also informs us of a change in the manuscript presentation from what Lewis originally wanted. The short canon was supposed to follow this table rather than precede it. The *signe-de-renvoi* leaves little doubt about this. This small error shows that *BLa* may not have been the final version of the *opera omnia,* but rather an intermediate copy.

The canon begins with a justification of the elaboration of the canon. The main reason for constructing a new table of the equation of time was that the one found in the Toledan Tables was obsolete for Lewis's time due to the precession of the equinoxes.[88] This brief passage is then followed by a definition of the equation of time. Lewis then describes the procedure for calculating the table that is discussed below (Sect. 5). Several sources are explicitly mentioned in the canon, such as Ptolemy's *Almagest* III.9, Azarchel (al-Zarqālī), i.e., the Toledan Tables, al-Battānī,[89] Jābir ibn

[85] *BLa,* p. 118.

[86] *BLa,* p. 119.

[87] *BLa,* p. 121.

[88] In his canon for the equation of time Lewis states: "Quia tabula communis equationis dierum quam composuit Azarchel nunc propter lapsum temporis transit in errorem propter longinquam remotionem augis Solis." See Appendix A. On the different tables of the equation of time found in the Toledan Tables tradition, see Pedersen (2002), pp. 968–977.

[89] See below Sect. 4.

Aflaḥ (Gebir) and Simon Bredon.[90] However, Lewis states that his table is particularly based on Ptolemy, al-Battānī, and Simon Bredon's commentary on the *Almagest*:[91]

> Ista vero tabula a diversitate diversimode componitur, ut patet per Ptholomeum, Albategni et Bredon libro suo 2° super Almagestum, qui tradit ibidem doctrinam completam de eam.

In this passage, Jābir ibn Aflaḥ is not mentioned, although at the end of the treatise, Lewis refers to him in addition to the three other authors to know more about the equation of time.[92] Despite this claim of intellectual lineage, the last paragraph in fact highlights Lewis's main source, which is Simon Bredon's *Commentum super Almagesti*. Indeed, he acknowledges that Simon Bredon covers the doctrine of Ptolemy, Jābir ibn Aflaḥ and al-Battānī:

> Si vero cupis habere latiorem tractatum de ista materia, vide Ptholomeum, Albategni, Gebir et Bredon. Sed Bredon in fine libri sui secundi super Almagestum comprehendit sententias omnium illorum et ponit ibi modum meum hic prescriptum in virtute, quamvis non ita plane, et ibi tradit doctrinam completam et perfectam de equatione dierum. Sed hoc ad presens sufficit.

This close reliance on Simon Bredon's commentary is supported by Lewis's surviving manuscripts. The physician not only relied on Simon but borrowed passages from his *Commentum super Almagesti,* Book III, rather than Book II as Lewis claims.

4.2 Lewis of Caerleon and Simon Bredon

In his introduction to the *Opus eclipsium*, Lewis praised four astronomers on whom he relied extensively, two ancients, Jābir ibn Aflaḥ and al-Battānī, and two moderns, Richard of Wallingford and Simon Bredon, both said to be former fellows of Merton College, although only Simon was there.[93] As Lewis mentions, it is probably mainly thanks to Simon Bredon that he had access to most of his sources.

90 *Almagest,* III.9; for al-Battānī see Nallino, *al-Battānī,* II, p. 61–64; for the Toledan Tables tradition, see Pedersen (2002), 968–977; for Jābir ibn Aflaḥ's *Iṣlāḥ al-Majisṭī or Liber super Almagesti* in the Latin translation by Gerard of Cremona, see Jābir ibn Aflaḥ, *Liber super Almagesti,* Peter Apian (ed.), *Instrumentum primi mobilis* (Nuremberg: Johannes Petreius, 1534); and for Simon Bredon, see the edition below.

91 As we show below in Sect. 5, Lewis's also used the solar equation, a necessary ingredient for the equation of time, from John of Lignères's tables, which is identical to the Alfonsine solar equation.

92 It is noteworthy that Lewis Caerleon for his computation of the solar eclipse of 28 May 1481 obtained the correction by the equation of time from the Toledan Tables and John of Lignères's Tables of 1322.

93 *BLa,* p. 39: 'Hiis visis, inter omnes astronomie professores tres mihi autores elegi inter quorum sentencias modica et quasi insensibilis restat dissonantia, quorum unum ex antiquis elegi Albategni qui in subtilitate observationis et precipue in opere eclipsium omnis suos antecessores excessit, cui etiam concordat Geber ac insuper commentator super Almagesti; duos etiam ex modernis elegi, qui in novissimis nostris diebus in excellentia et subtilitate demonstrationum omnes suos contemporaneos in toto orbe terraris sparsum florentes eximie superarunt, ut ex eorum operibus manifeste liquet Magistrum Symonem Bredon et Ricardum Wallyngforth abbatem Sancti Albani, utrumque anglicum atque quondam socios collegii de Merton Oxonie verum valde sum gavisus quod nostre nationis viri studiosi in mathematicis floruerint.'

Simon Bredon (d. 1372) was a fellow of Merton College from 1330 to 1341.[94] He was educated in theology and then in medicine (likely between 1341 and 1348) at the University of Oxford. During his time in Oxford, he was highly committed to Merton College and the University governance. His role as a mentor to other fellows, such as William Reed (d. 1385), or John Ashenden (d. *c.* 1368) is evidenced by his will, manuscript exchanges, the granting of mutual favours and other mentions.[95] He seems to have been an authority on astronomy to his contemporaries.[96] After he left Oxford, he maintained life-long relationships with a certain number of former fellows, particularly William Reed and William Heytesbury (d. 1372/1373). After 1348, Simon held various ecclesiastical benefices but also acted as a physician of the Earl of Arundel and Joanna, Queen of Scotland. He also benefited from the patronage of the Earl of Arundel and the archbishop of Canterbury.

His own writings, mainly on the mathematical sciences, were produced while he was still at Oxford. His most important work is his commentary on the *Almagest,* Books I–III, which was written around 1340,[97] contemporary with William Reed's adaptation of the Alfonsine Tables to the Oxford meridian (1340) and the *Almanak Solis,* on which Simon may have collaborated.[98] It is not certain that Simon Bredon commented on the other books of the *Almagest.* Two manuscripts display a large part of the commentary.[99] The earliest witness is Simon's autograph copy probably made in Oxford. However, Oxford, Bodleian Library, MS Digby 168, fols. 21r–39r is incomplete; it contains books I–III with I.3–12 and the beginning of the second book missing. Another copy may be found in MS Digby 178, which was commissioned by Lewis Caerleon and annotated by him. Simon Bredon's commentary is contained on fols. 39r–86v, beginning with Book I.9–11 and displaying a full version of Books II and III.

94 On Simon Bredon, see C. H. Talbot, 'Simon Bredon (c. 1300–1372): Physician, Mathematician and Astronomer', *The British Journal for the History of Science 1* (1962), 19–30; R. Lorch, 'Jābir ibn Aflaḥ and the Establishment of Trigonometry in the West', in R. Lorch, *Arabic Mathematical Sciences. Instruments, Texts, Transmission* (Farnham-Burlington, 1995), VIII, 30–31; K. Snedegar, 'The Works and Days of Simon Bredon, a Fourteenth-Century Astronomer and Physician', in *Between Demonstration and Imagination. Essays in the History of Science and Philosophy presented to John D. North*, eds L. Nauta, A. Vanderjagt (Leiden, Brill Publishers, 1999), 285–309.

95 For Simon Bredon's will, see F. M. Powicke, *The Medieval Books of Merton College* (Oxford: Clarendon Press, 1931), pp. 82-86; for other evidence see Snedegar (1999).

96 John Ashenden refers to Simon Bredon who is said to have equated the motion of the eighth sphere *c.* 1340: Oxford, Bodleian Library, Digby 176, fol. 45r: 'Ista patent secundum magistrum Simonem de Bredone qui circa annum Christi 1340 equavi motum octave sphere cum maxima diligentia'.

97 On Simon's *Commentum super Almagesti,* see: Zepeda (2013), pp. 282–301, who provides an edition of the first two books; see also Zepeda (2018), pp. 95–98.

98 On William Reed's adaptation to the Alfonsine tables, see: R. Harper, 'The Astronomical Tables of William Rede', *Isis,* 66 (1975), 369–78; John D. North, *'The Alfonsine Tables in England',* in *ΠΡΙΣΜΑΤΑ: Naturwissenschaftsgeschichtliche Studien. Festschrift für Willy Hartner,* ed. by Y. Maeyama and W.G. Saltzer (Wiesbaden, 1977), 269–301; J. Chabás, *Computational Astronomy in the Middle Ages: Sets of Astronomical Tables in Latin* (Madrid, 2019), Chapter 10; on the Almanak Solis, see Jean-Patrice Boudet and Laure Miolo, 'Alfonsine Astronomy and Astrology in Fourteenth-Century Oxford: The Case of MS Bodleian Library Digby 176', in Richard Kremer, Matthieu Husson and José Chabás (eds), *Alfonsine Astronomy: The Written Record* (Alfonsine Astronomy, 1), (Turnhout: Brepols, 2022), 57–106.

99 See the detailed discussion in Zepeda (2018), pp. 95–98; David Juste, *'Simon Bredon, Commentum super Almagesti'* (update: 16.06.2022), *Ptolemaeus Arabus et Latinus. Works*, URL = http://ptolemaeus.badw.de/work/76 [accessed 20 July 2023].

In Digby MS 178, Book I.9–11, is copied as an independent and anonymous text following Richard of Wallingford's *Quadripartitum* and a long autograph note by Lewis (fols. 38r–v). Book I.12 opens on fol. 42r with the following running title added by Lewis's hand: 'Commentum Magistri Symonis Bredon super aliquas demonstrationes Almagesti'. It seems that Lewis had access to another witness which contained Book I.9–11 and that he did not understand that it was part of Simon's commentary. The other portion of the manuscript displaying Book I.12–Book III (MS Digby 178, fols. 42r–86v) was probably copied from MS Digby 168 and clearly displays the identity of the author. The third and last surviving copy of the *Commentum super Almagesti* is preserved in Lewis's notebook, *CUL*, fols. 43r–45r, where only an excerpt from Book I is copied by Lewis himself under the title: 'Expositio Symonis super quedam capitula *Almagesti* Ptholomei'.[100]

Alongside the *Commentum super Almagesti,* Lewis possessed a copy of what was probably the first treatise written by Simon Bredon in the 1330 s, a commentary on Boethius's *De institutione arithmetica*. This text was copied and annotated by Lewis in his notebook.[101] It is not impossible that Lewis also had in his possession the volume once kept in Clare College in Cambridge containing Simon's table of chords and a part of his commentary on the *Almagest.*

Lewis's familiarity with Simon Bredon's works shows that he likely had easy access to his manuscripts. Indeed, he was probably in Oxford after 1466, and perhaps even at Merton College, as evidenced by his gift in 1490.[102] Additionally, during Lewis's time, Richard Fitzjames (d. 1522) was a Fellow of Merton College and then Warden (1483–1507) and showed some interest in the science of the stars. Both men were also in the entourage of Henry VII.[103] In the late fifteenth century, Simon Bredon's volumes on which Lewis relied were still in Merton College having been bequeathed by the former fellow in 1372. Indeed, Lewis's exemplar of Simon Bredon's *Commentum super Almagesti* was likely directly copied from MS Digby 168 as there is little variation between both texts. But there is more: his copy of Richard of Wallingford's *Quadripartitum* (MS Digby 178, fols. 15r–38r) is also based on MS Digby 168, fols. 1r–13v, as is the case for the *Tractatus rectanguli* copied by Lewis in his notebook (*CUL*, fols. 8r–12r) and based on MS Digby 168, fols. 61va–64va. Most of Lewis's sources are thus displayed in Simon Bredon's manuscripts. One may also assume that Lewis had access to the *Albion* and to Jābir ibn Aflaḥ's *Liber super Almagesti* with another volume of Simon Bredon which originally included MS Digby 178, fols. 1r–14r and fols. 88r–115v, BL, Harley MS 625 and Cotton MS Tiberius B IX, fols. 1r–4v.[104] Indeed, no manuscripts in Lewis's possession containing the *Albion*, one of

100 *CUL*, fol. 43r.

101 *CUL*, fols. 95v-105v.

102 Converging evidence is provided by his interest in other Mertonian works, such as those of John Killingworth or the lesser-known John Curteys and Walter Hertt, who probably belonged to the same group of scholars. Miolo (2024).

103 Cf. Carey (2012).

104 Cf. Watson (1976), pp. 207–217; see also David Juste, 'MS London, British Library, Harley 625' (update: 24.03.2022), Ptolemaeus Arabus et Latinus. Manuscripts, URL = http://ptolemaeus.badw.de/ms/206 [accessed 10 July 2023].

his main sources, have survived, and we can assume that he had access to it through another source, which could very well have been Simon Bredon's manuscript.

Although Richard of Wallingford was Lewis's source for his eclipse tables, he relied on Simon Bredon for spherical astronomy. In addition to the table of sines and chords, which Lewis expanded from a table ascribed to Simon, it is for his solar declination table and his derivation of the obliquity of the ecliptic that he is praised. In the introduction to the tables of right and oblique ascension, Lewis also mentions several sources, such as Ptolemy, al-Battānī,[105] Jābir ibn Aflaḥ (Geber),[106] and John Holbroke.[107] However, it is Simon Bredon who is the most frequently mentioned and whose values are retained by Lewis. The latter indeed alleged to have found the same maximum solar declination (obliquity of the ecliptic), 23;28,17°:

> [...] noster enim Bredon geometer et astronomus eximius invenit eam [obliquity of the ecliptic] 23 gradus 28 minuta et 17 secunda. Ego novissimus et omnium minimus inveni eam quodmadmodum Bredon fere hic prescripti primum ante. Et quia magister Symon Bredon fecit novam tabulam declinationis solis ac ascensionis signorum in circulo recto et, adhuc in diebus nostris, maxima solis declinatio a positione sua insensibiliter variatur, ideo non est opus novas tabulas declinationis nec ascensionum in circulo recto construeri.[108]

According to Lewis's note, this value is taken from Simon Bredon's table of solar declination. Interestingly, a solar declination table explicitly attributed to Simon is in BL, Egerton MS 889, fol. 18v a manuscript partly copied by John Holbroke before 1426 and containing his *Opus primum* and *Opus secundum*.[109] Lewis likely copied his copy of John Holbroke's tables from Egerton MS 889 (hereafter E_2) and knew about this table.[110] However, the table is given in minutes only and does not allow the reader to infer the maximum solar declination in seconds.

For the equation of time, there is little doubt that Lewis relied entirely on Simon's *Commentum super Almagesti*, especially Book III. 22–24.[111] Passages are taken directly from it without change, as we demonstrate in Appendix C. Furthermore, given the sources Lewis cites in his canon of the equation of time, it is remarkable that he was unaware that Simon Bredon follows the *Almagesti minor*.[112] This is probably

105 *BLa,* pp. 46–47.

106 *BLa,* p. 47.

107 *BLa,* p. 49.

108 *BLa,* p. 46; in the portion dedicated to the table of right ascension, p. 48, Lewis again stated that he relied on Simon Bredon: 'Inventio eiusdem differentie per maximam declinationem Bredon and meam, sicilitet 23 degrees, 28 minuta, 17 secunda'.

109 On this manuscript, see David Juste, 'MS London, British Library, Egerton 889' (update: 23.02.2023), *Ptolemaeus Arabus et Latinus. Manuscripts*, URL = http://ptolemaeus.badw.de/ms/50 [accessed 20 July 2023]; on John Holbroke and his set of tables adapted to the meridian of Cambridge: C. P. E. Nothaft, 'John Holbroke, the Tables of Cambridge, and the "True Length of the Year": a Forgotten Episode in Fifteenth-Century Astronomy', *Archive for History of Exact Sciences* 72 (2018), 63–88; the declination table is in BL, Egerton MS 889, fol. 18v and is entitled 'Tabula declinationis solis secundum Bredone'.

110 Nothaft (2018), p. 66.

111 Simon Bredon deals with the equation of time in Book III.19-24.

112 Cf. Zepeda (2018), pp. 97–98, for the equation of time, the source is the *Almagesti minor* Book III 20-25, see pp. 264–275.

because the only sources cited by Simon in Book III 22–24 are al-Battānī's equation of time table found in the Toledan Tables and Ptolemy's *Almagest.* It is likely that the absence of an explicit mention of the *Almagesti minor* in the commentary prevented it from coming to Lewis's attention. Indeed, Lewis tends to mention second-hand the authorities cited in his own sources, as is the case with Richard of Wallingford's *Albion*, his source for his *Opus eclipsium*, from which he borrowed the values given in the *Almagesti minor*, al-Battānī and Jābir ibn Aflaḥ.

The sections dedicated to the equation of time in Simon's *Commentum super Almagesti* are covered by chapters 22 to 24 of Book III. Chapter 22 focuses on finding the place from which the inequality of days arises and explaining the cause of this inequality. This mainly derives from the *Almagesti minor,* III, 21–22.[113] In Chapter 23, Simon Bredon deals with the difference between mean days and apparent days resulting from two causes, the solar anomaly and the variation in the time of meridian-crossing. This allows us to find the beginning of the addition or subtraction from the mean day as described in the *Almagesti minori* III, 24.[114] At the end of this section, Simon Bredon, after mentioning that the table for the equation of time of al-Battānī is mistaken for not being perpetual, adds a long development on how to make a perpetual table for the equation of time:[115]

> Et ideo tabula Albategni facta pro equatione dierum non potest esse perpetua, immo per lapsum temporis erit falsa.
> Docebo tamen tabulam unam componere, que una cum tabula ascensionum in circulo directo, pro diebus equandis deserviet in eternam.

Despite the details provided by the author, the whole section was deleted by the notes of *vacat* written in the margins. In his own copy (MS Digby 178), Lewis Caerleon remains faithful to Simon's instructions and does not include this passage. This deletion is probably because Simon Bredon realized that it was not possible to construct a perpetual table for the equation of time. Therefore, after deleting this whole passage, he came back to his text and immediately after Chapter 24 included a revised version of the rule for computing a table for the equation of time. Indeed, most of the material borrowed by Lewis is found in the *Commentum super Almagesti* Book III.24 devoted to the conversion of apparent days into mean days and vice versa. The beginning of the chapter is quite similar to what we find in the procedure described in the *Almagesti minor* Book III.25.[116] However, in Simon Bredon's commentary it is followed by a whole method for making a table of the equation of time, quite different to the one added after Chapter 23 and then deleted:

> Iste igitur est modus convertendi dies mediocres in dies differentes, quod si volueris econtra convertere operaberis econverso. Et est notandum quod per istum modum precisissime fieri patet tabula equationis dierum que licet non poterit esse perpetua operando tamen cum ea per 100 annos insensibilis erit error.

113 Zepeda (2018), pp. 266–270.

114 Zepeda (2018), pp. 271–272.

115 Cf. MS Digby 168, fols. 38r-v.

116 *Almagesti minor,* III.25, see Zepeda (2018), p. 273–275.

Inquiratur igitur in linea numeri tabule equationis solis gradus correspondens 18 gradui Aquarii, eo quod a principio illius gradus incipit.[117]

It is this very method that Lewis follows for his own table.

5 Tables of the equation of time in mathematical astronomy

From Ptolemy's *Almagest* to Copernicus' *De revolutionibus orbium coelestium* and beyond, time in mathematical astronomy is measured in mean solar time, with days spanning from one mean noon to the next. Civil and daily life, however, was ordained by apparent solar time that could be read from a sundial, with days spanning from one meridian crossing of the true Sun to the next. The concept of mean time assumes a uniform solar motion throughout the year, and neglects the fact that the diurnal rotation is in the plane of the celestial equator and not in the plane of the ecliptic. Apparent solar time is based on the apparent motion of the Sun and, thus, takes into account that solar motion throughout the year slightly varies and that equal arcs of the ecliptic do not rise with equal arcs of the equator. This difference between mean solar time and apparent solar time is captured by the equation of time. It is considerably small on a daily basis but can amount to about 30 min of time over the course of a year. Therefore, as Lewis knew, the equation of time is an essential component in the computation of eclipses, for the moon is moving rather fast.

In his *Almagest*, Ptolemy employed the equation of time to transform celestial observations recorded in apparent time into mean time, in order to make use of these observations for the determination of parameters in the geometric models of lunar motion.[118] However, Ptolemy did not include a table for the equation of time in the *Almagest*. However, his *Handy Tables*, compiled later than the *Almagest*, do contain such a table intended to correct apparent solar time to mean solar time.[119]

Later sets of astronomical tables usually do also contain tables for the equation of time. Most of these tables are constructed in such a way, that apparent time is derived from mean time by adding the equation of time to the latter. In order to do so, it is essential to know the position of the true Sun for the day or moment under consideration. With the position of the true Sun, one enters the table for the equation of time and adds the corresponding value to mean time to obtain apparent time. Vice versa, to find mean time from apparent time, the equation of time is subtracted from the latter. Tables for the equation of time were predominantly used to transform computed times of true syzygies from mean time into apparent time or, in rare cases, for astrological purposes related to the determination of a specific moment in time.[120] In his eclipse canons, as we have stated above, Lewis explicitly referred to the use of the equation

117 MS Digby 168, fol. 38v; MS Digby 178, fol. 85v.

118 On the equation of time in the *Almagest*, see Toomer (1984), 169–72. For a mathematical discussion, see Neugebauer (1975), 61–65. See also Pedersen 2010, 154–58. Ptolemy, e.g., uses the equation of time in *Almagest* IV:6 when he determines the first lunar anomaly from three eclipse observations. See Toomer (1984), 190–203. For more details see, Neugebauer (1975), 73–78. Pedersen (2010), 167–73.

119 For the table, see Stahlmann (1960), 206–9. For a modern analysis of this table, see van Dalen (1994).

120 For example, in his nativity of Maximilian I, Regiomontanus corrected the time of birth by the equation of time, see Andriani, Zieme (2024).

of time when computing times of true syzygy. In addition, in fact, he did apply the correction by the equation of time, when computing the eclipses of 28 May 1481 and 16 March 1485. For the computation of the eclipse of May 1481, for example, Lewis compared two different tables for the equation of time, which he attributed to al-Zarqālī (Toledan Tables) and John of Lignères (Tables of 1322).[121] Moreover, in the canons to his own table of the equation of time, given in Appendix A, Lewis quotes two different maximum values of two different tables of the equation of time as 7;54° and 7;57°, which he attributes to al-Zarqālī and al-Battānī, respectively.[122] In fact, the first value, 7;54°, clearly corresponds to al-Battānī's table of the equation of time and was part of his *Ṣābiʾ zīj* that he compiled around the year 900.[123] This table occasionally circulated in manuscripts with astronomical tables of the Alfonsine corpus. However, it predominantly circulated with the Toledan Tables that were completed around the year 1080.[124] For the latter reason, Lewis most probably, yet falsely, attributed the table to al-Zarqālī. The second value, 7;57°, clearly corresponds to the table of the equation of time attributed today to Peter of St. Omer (fl. 1293).[125] This table was also included by John of Lignères in his Tables for 1322.[126] In manuscript tradition, the tables of the Alfonsine corpus most frequently circulated with this table of the equation of time.[127] That Lewis attributed it to al-Battānī might indicate that he assumed that John of Lignères had borrowed it from al-Battānī, or he simply made a mistake. Be that as it may, Lewis was aware of different tables of the equation of time that, according to his attribution, were computed some 400 years before his own time. Differences in these tables, as Lewis states in the canons (see Appendix A), arise from the motion of the solar apogee. Therefore, as the centuries pass and the solar apogee advances, the table of the equation of time needs to be recomputed. Especially for reliable eclipse computations, the main concern of Lewis's astronomical writings as we have argued in Sect. 2, a more or less up-to-date table of the equation of time was essential. Therefore, Lewis computed a novel table for the equation of time, such that, as he phrased it himself (see Appendix A), when "operating with it for 100 or 200 years, the error will be insensible."

Other Alfonsine astronomers who compiled eclipse tables also computed novel tables for the equation of time. In his examples included in the canons to his *Tabulae eclypsium*, for example, Giovanni Bianchini (c. 1410–69) corrected the times of true syzygy by the equation of time.[128] In his planetary tables, compiled around 1442 and

121 Miolo (2024).

122 Both tables are found in E_2 (fols 38v, 138r, 118v) to which Lewis might have had access. On this manuscript, see David Juste, *'MS London, British Library, Egerton 889'* (update: 23.02.2023), *Ptolemaeus Arabus et Latinus. Manuscripts*, < http://ptolemaeus.badw.de/ms/50 > (consulted 25 July 2023).

123 For the table, see Nallino (1903), II, pp. 61–64.

124 Pedersen (2002), III, pp. 968–77.

125 Pedersen (2002), III, pp. 984–85.

126 Chabás, Saby (2022), 72–75.

127 The first printed edition of the Parisian Alfonsine Tables, printed by Erhard Ratdolt in Venice in 1483, however, included al-Battānī's table for the equation of time included in a table of normed right ascension. See *Tabule astronomice illustrissimi Alfontij regis castelle* (Venice: Ratdolt 1483), ff. k1r-k2r.

128 Chabás, Goldstein (2021). In Bianchini's example for the solar eclipse of July 1460, he corrects the time of true conjunction by 12 min, with the true Sun at 123;59°. This is in agreement with both Bianchini's

first printed in 1495, which are known under the title *Tabulae astronomiae*, Bianchini included al-Battānī's old table of the equation of time that he converted from time-degrees into minutes and seconds of hours. Although this simply corresponds to a multiplication by four, the table of the equation of time thereby became ready to use for the determination of times of solar eclipses and other astrological purposes.[129] Later, Bianchini computed his own modern table of the equation of time, made for his period of time, that circulated with his updated version of his *Tabula primi mobilis*, denoted version B.[130] In most manuscript copies the corresponding table was usually presented with a title that explicitly stated that the equation of time was computed for the year 1456 with the solar apogee at 90;46° ecliptic longitude.[131]

Georg Peurbach (1423–61) also included a novel table of the equation of time in his *Tabulae eclypsium*. These eclipse tables were compiled around 1460 and first appeared in print in 1514 in Vienna.[132] In his example computation for the eclipse of July 1460 included in the canons, Peurbach likewise corrected the time of true syzygy by the equation of time.[133] The table of the equation of time contained in his eclipse tables, most likely, was computed according to a specific algorithm developed by Regiomontanus that employed a computational scenario tailored to the use of Bianchini's planetary tables.[134] In most manuscript witnesses of Peurbach's eclipse tables, but also in the printed edition, the table of the equation of time is accompanied by a title that emphasizes its novel constitution and also indicates some of the underlying parameters used, like the position of the solar apogee and the obliquity.[135]

From a historical perspective the equation of time is a valuable object, because it is one of the few quantities that was newly computed every now and then in mathematical astronomy. Especially for the period of Alfonsine astronomy, where most models and parameters were stable and tables were only changed in their layout or their organizational structure, the table of the equation of time and especially its computation offers valuable insights into the transmission of parameters and mathematical practices.

Modern analysis, so far, has focused on determining implicit parameters contained in the table of the equation of time. A modern formula that captures the equation of

Footnote 128 continued
old, adapted from al-Battānī, and modern table of the equation of time mentioned below. For the lack of seconds given in the example, we cannot distinguish between these two tables.

129 Note that the 1495 printed edition does not contain this table. See, Chabás, Goldstein (2009), 100–3.

130 On Bianchini's *Tabula primi mobilis*, see van Brummelen (2018). See also, Chabás (2019), 353–58. On versions A and B, see van Brummelen (2021).

131 There are at least two manuscripts (Paris, BnF, lat. 7268, ff. 139v and Bologna, Biblioteca Comunale, MS 1601, fol. 72r) that state the year 1460 for the table. Apparently, this is a scribal error because the solar apogee of 90;46° is identically given for the year 1456 in Bianchini's planetary tables. See, e.g., Giovanni Bianchini, *Tabulae astronomiae* (Venice: 1495), f. b2v.

132 Chabás (2019), 365–75.

133 Georg Peurbach, *Tabulae eclypsium* (Vienna: Johann Winterburger, 1514), fols bb5v–bb7r. Peurbach corrects the time of true conjunction of 17 July 18;3 h by 12 min. With the true sun at 123;58,32° this is in agreement with his own table for the equation of time. For the lack of seconds, however, it would also agree with both Bianchini's old and modern table.

134 Andriani, Zieme (2024).

135 Peurbach, *Tabulae eclypsium*, d5r: "Tabula Equationis dierum novissime constituta presupponens Augem solis in principio Cancri Et Declinationem Allmeonis." See, e.g., also Nuremberg, Stadtbibliothek, Cent V, 57, fol. 143v.

time E as a function of true solar longitude λ is given by[136]:

$$E(\lambda) = \frac{1}{D}(\lambda + q(\lambda - \lambda_{\text{aux}}, e) - \alpha(\lambda, \varepsilon) + c). \tag{1}$$

Here, the function $q(\lambda)$ denotes the solar equation as a function of true anomaly, which depends on the solar eccentricity e, with λ_{aux} the ecliptic longitude of the solar apogee. The function $\alpha(\lambda)$ denotes the right ascension that depends on the obliquity ε of the ecliptic. The constant c is the so-called epoch constant related to the positivity of the equation of time. The conversion factor D captures if the equation of time is expressed either in degrees or in hours of time. Since all the involved functions exhibit different symmetry relations, inherited by $E(\lambda)$, all parameters e, λ_{aux}, ε, and c may be reliably determined statistically by the method of least-squares.[137] Based on the modern formula (1), it is a straightforward task to determine the underlying parameters for a given table of an equation of time by solving the non-linear least squares problem.[138]

An apparent drawback of modern analysis, however, is that it contains the solar equation as a function of true anomaly, which is not attested in historical sets of astronomical tables. The latter exclusively contain the solar equation as a function of mean anomaly. Therefore, despite obtaining parameter estimates, modern analysis may not draw any conclusion about underlying mathematical practices.

One of our aims in this article is to analyse the underlying mathematical practices of Lewis's table of the equation of time. By investigating the computational scenario employed by Lewis we will be able to identify sources that he consulted, identify variants of sub-tables that he used, or even identify specific manuscripts that he may have consulted. This focus on computational scenarios adds a new historiographical tool to the history of astronomy that may enrich the mapping and transmission of astronomical knowledge across space, time, and culture.[139]

6 Lewis's calculation of the equation of time

The newly computed table by Lewis for the equation of time is uniquely contained in *BLa* on page 121, according to the modern pagination, and is reproduced in Fig. 1. It bears the title "*Tabula equationis dierum in motu et in tempore per me Lodowycum Caerlyon noviter facta anno domino 1485 in turre Londoniarum.*" As is common for most tables for the equation of time, the values are tabulated individually for each of the thirty integer degrees of a sign, for all twelve signs of the zodiac.[140] The table is

[136] Van Dalen (1996).

[137] For the equation of time, this method was first introduced by van Dalen (1993), 97–152. For modern mathematical formulas for the solar equation and right ascension, as well as a detailed discussion of the parameters, see also van Dalen (1994, 1996).

[138] There are several software packages that readily include different algorithms to solve non-linear least squares problems, like *Mathematica*, *SciPy* (*Python*), or *Matlab*.

[139] For another example of computational scenarios related to the equation of time, see Andriani, Zieme (2024).

[140] For some historical examples of tables of the equation of time, see Chabás, Goldstein (2012), 37–41.

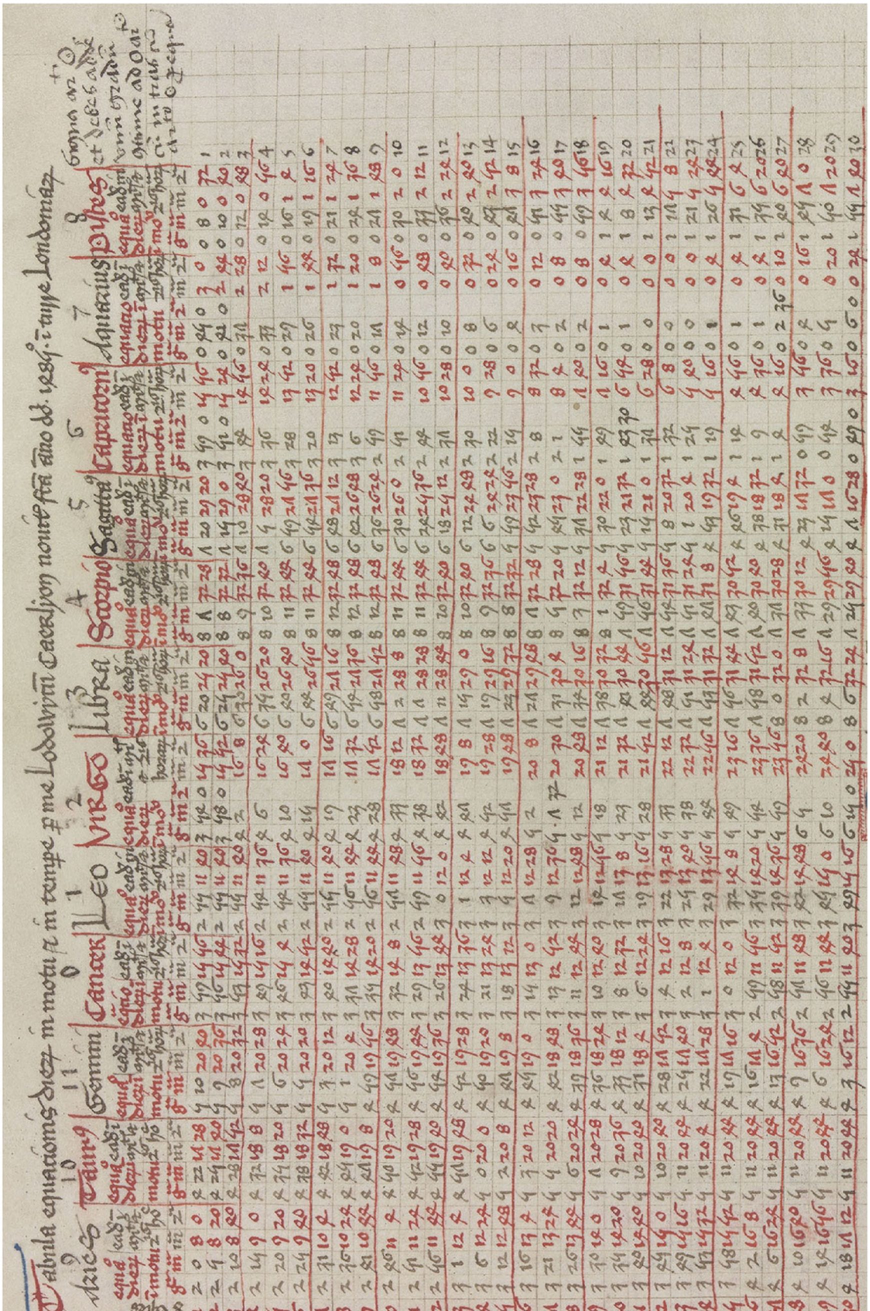

Fig. 1 Lewis's table for the equation of time. The British Library, Add MS 89442, p. 121

presented as a standalone, without right ascension that is sometimes displayed jointly with the equation of time, and starts with the first degree of Aries. A later, different hand consecutively added one of the twelve numbers 9, 10, 11, 0, 1, 2, …, 8 on top of the zodiacal signs starting from Aries (9) to Pisces (8).[141] In the margin, probably added by the same later hand, there is a note "*signa argumenti* ⊙ *et debes addendum unum gradum continue ad* ⊙ *argumentum in cum intras cum argumento* ⊙ *pro equa.*" Exceptional for Lewis's table is that the individual values for the equation of time are given in both, time-degrees and hours of time. Clearly the latter values in hours of time, given to minutes and seconds, are derived from the former values in time-degrees, given to degrees and minutes, simply by multiplication by four.[142] Therefore, the seconds of the values given in hours of time are multiples of four. In the three columns for Virgo, Capricorn, and Aquarius; however, the values for the equation of time in time-degrees have an additional sub-column for seconds. In each of these three sub-columns there is exactly one non-zero value, which indeed is given to seconds of time-degrees with an absolute value around 30 s. Apparently, in these three cases, Lewis has computed with an increased precision to seconds to reduce the error from rounding. Therefore, the three corresponding values for the minutes given in hours of time are not multiples of four but multiples of two.[143] In the remaining 357 cases, all values for hours of time are multiples of four and are correctly computed from the values given in time degrees.[144] Like for every table of the equation of time there are four maxima that may serve to classify the particular table. Lewis's equation of time has a maximum of 5;11° (20;44 min) at Taurus 23°–30°, a minimum of 2;55° (11;40 min) at Cancer 30°–Leo 3°, a second maximum of 8;12° (32;48 min) at Scorpio 7°–9°, and a second minimum of 0;0° (0;0 min) at Aquarius 21°–23°. As already indicated by its title, this table is indeed unprecedented and newly computed by Lewis. From our first visual inspection of the table, especially with regard to the three cases with increased precision, we might infer that Lewis was a very accurate and precise calculator.[145]

This assumption, of Lewis being an accurate calculator, is immediately verified when we perform a non-linear multiparameter fit of his table for the equation of time using the modern formula (1). From our preceding discussion of the table, we already inferred that the conversion factor is given by $D = 15°/\mathrm{h}$. For the non-linear fit, we used all 360 values of the equation of time given in hours of time, thus, without assuming any underlying interpolation grid.[146] The result is summarized in Table 1.

141 These numbers indicate that the later annotator of the manuscript most likely compared Lewis's table with a different table for the equation of time that was included in a table of normed right ascension that starts in Capricornus. Such a table for the equation of time is, e.g., contained in London, British Library, Egerton MS 889, fol. 118v, which is attributed to al-Battānī, though with signs numbered from 1 to 12.

142 The conversion factor from time-degrees into hours of time is, as usual, given by 360°/24 h = 15°/h. In sexagesimal numbers this corresponds to multiplication by four and shifting by one sexagesimal place.

143 See, respectively, Virgo 17°, Capricornus 20°, and Aquarius 27° in the table reproduced in Fig. 1.

144 There is only one obvious scribal error at Taurus 24° where the value in hours of time is wrongly written as 20;4 min instead of the correct value 20;44 min.

145 His talent for calculation is also highlighted in North (1977), 290.

146 We solved the non-linear least squares problem with *Mathematica* using the Levenberg–Marquardt algorithm. Given the fact, that the starting values for the fit are well constrained from historical context, the convergence is excellent. Therefore, it is rather irrelevant which algorithm is used in the least square fit, results are identical.

Table 1 Parameter estimates for Lewis's equation of time based on modern analysis

Parameter	Best-fit value	95% confidence interval
Eccentricity e [°]	02;16,04	02;15,59–02;16,08
Apogee λ_{aux} [°]	90;58,33	90;56,44–91;00,21
Obliquity ε [°]	23;35,10	23;34,52–23;35,29
Epoch constant c [°]	04;04,47	04;04,44–04;04,50

The confidence intervals for the parameters fit perfectly well with historically attested values. The interval for the solar eccentricity e leaves no doubt that Lewis used the table for the equation of the Sun from the Parisian Alfonsine Tables, as we would expect. The solar apogee with a longitude of around 91° indeed corresponds to a time around 1485 for which Lewis explicitly states he computed the table.[147] From the interval for the obliquity we further conclude that Lewis appears to have used a common table of right ascension that is based on an obliquity of $\varepsilon = 23;35°$, attributed to al-Battānī, and that circulated widely with the Parisian Alfonsine Tables as well as with the Toledan Tables.[148] This is quite surprising, because Lewis took some pains to derive a novel table of right ascension that is based on an updated obliquity of $\varepsilon\prime = 23;28,17°$ that he and Simon Bredon attested for their own time. This new table of right ascension and its derivation is also included in the same manuscript with Lewis's new table for the equation of time.[149] Why he would not use his novel table of right ascension for his novel table of the equation of time must remain unanswered. Perhaps Lewis derived the new table of right ascension only after he recomputed the equation of time or he simply had no access to his own table of right ascension during his imprisonment in the Tower of London, where he stated he computed his table of the equation of time.

When we employ historically attested and plausible values for the parameters, i.e. the obliquity $\varepsilon = 23;35°$, the solar eccentricity $e = 2;16,4$, the longitude of the solar apogee $\lambda_{aux} = 91°$, and keep the best-fit value for the epoch constant $c = 4;4,47°$, for which there is no historical equivalent, we find perfect agreement between Lewis's table and the modern formula: the curve of the residuals that results from subtracting Lewis's values from the modern computation is plotted in Fig. 2. The standard deviation

147 From, e.g., Bianchini's *Tabulae astronomiae* we find for the year 1484 a solar apogee of 91;1,58°, which the Sun will reach on 12 June 22;51 h after mid-day. See, Giovanni Bianchini, *Tabulae astronomiae* (Venice: 1495), f. b2v. Bianchini's tables are based on the Parisian Alfonsine Tables, and we can confirm this value for the apogee by direct computation with the latter. On Bianchini and his astronomical tables, see Chabás, Goldstein (2009).

148 On al-Battānī's table of (normed) right ascension within the Toledan Tables, see Pedersen (2002), 3:968–75.

149 For Lewis's table of (normed) right ascension, see *BLa*, p. 53 (bottom half). The values are given to seconds for all integer degrees of the zodiac. Multiples of 5° are given to thirds. To derive this table (ibid., p. 53 upper half), Lewis first calculated right ascension for multiples of 5° for one quadrant to thirds using an obliquity of 23;28,17°. He then interpolated for all integer degrees of the quadrant to seconds. By symmetry the table is laid out for all signs. For the attribution of this obliquity to Simon Bredon and Lewis, see ibid., p. 48: "Inventio eiusdem differentie per maximam declinacionem Bredonis et meam scilicet 23;28,17." A non-linear fit of Lewis underlying 5°-grid-construction table for right ascension indeed confirms the use of this obliquity and results in an 95%-confidence interval of $< 23;28,17°–23;28,30° >$.

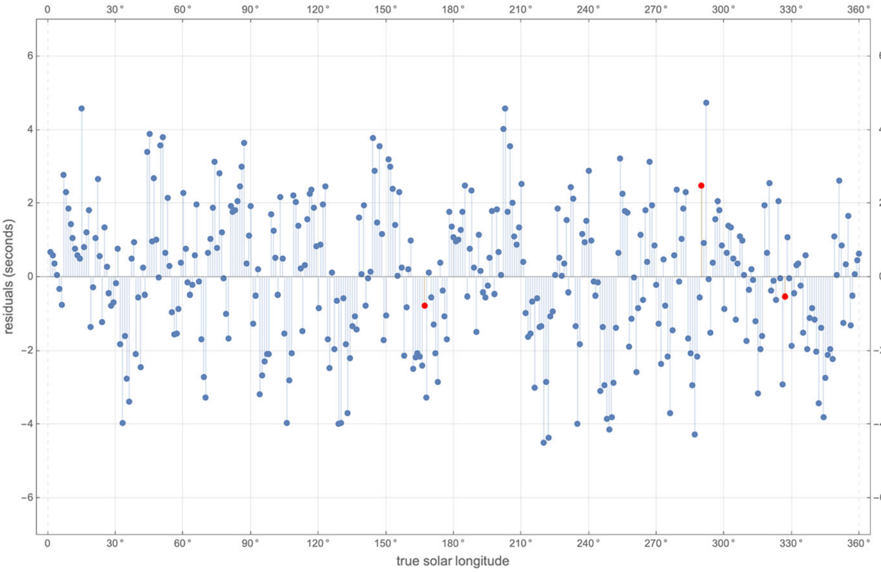

Fig. 2 Residuals of Lewis's table for the equation of time, given in hours of time, compared to a modern recomputation using historically attested values resulting from the confidence-interval of the non-linear fit. The three red data-points correspond to the values for 167°, 290°, and 327° for which Lewis used an increased precision

that corresponds to this fit amounts to 1;52,47 s. Given the fact that we used modern mathematics and a functional derivation compared to Lewis's possible use of other sub-tables and sexagesimal arithmetic, the agreement is very good.

So how did Lewis compute his table? Luckily, the exact details, including every step of his computation, are also included in *BLa*. On pages 119–120, right before the final table of the equation of time, there is a large table with intermediate results by which Lewis computed the table of the equation of time. Moreover, he also compiled a text, copied on page 118, that explains the nature of the problem and the necessary calculational steps. In the following we will analyze in detail Lewis's computational procedure in order to show that it is entirely different from modern understanding and skillfully shaped towards the use of tables for the solar equation and right ascension.

The intermediate table composed by Lewis in order to compute the equation of time has the title "*Compositio tabule equationis dierum per me Lodowycum anno Christi 1485 supponendo augem solis in primo gradu Cancri perfecto cuius compositionis canones proponuntur in proximo folio ad signum tale ⊙. Aux vera Solis in Cancri 1 gradu.*" The table has 8 columns and 362 rows. There is one row for each integer degree of the full circle, where two rows appear twice for reasons that will become clear immediately. The columns and their content are summarized in Table 2.

Table 2 Columns of the table with intermediate results

No.	Title	Content	Precision
1	*Medius motus solis*	Mean Sun	Deg
2	*Argumentum solis*	Mean solar anomaly	Deg
3	*Verus motus solis in Aquariis*	True Sun	Deg, min, sec
4	*Ascensiones circuli directi in pertransitione veri motus*	Right ascension true Sun	Deg, min, sec
5	*Differentia ascensionum et medii motus et est equatio dierum*	Difference between right Ascension plus mean motion (from radix) and right ascension	Deg, min, sec
6	*Gradus perfectus veri motus*	Integer longitude true Sun	Deg
7	*Equatio dierum correspondens*	Equation of time in time-degree	Deg, min, sec
8	*Idem in minutis et secundis horarum*	Equation of time in hours	Min, sec

Although the column for the equation of time in time-degrees has a sub-column for seconds, only two out of 362 values are given to seconds.[150] In total the intermediate table contains 5786 numbers. We have reproduced a section from the beginning of the table in Fig. 3.

Lewis's algorithm for computing the table for the equation of time comprises eight calculational steps. In addition to these eight steps it is necessary to find the "beginning of the addition" (*Principium additionis*) as it serves as the radix value or zero-point for the composition of the table. In conjunction with the intermediate table, the algorithm is explained in the canon of which we offer an edition and translation in the appendix. The algorithm for deriving the table for the equation of time can be summarized as follows, where the numbers in the numeration below correspond to the columns in the intermediate table and the symbol • corresponds to finding the point of the beginning of the addition:

1. Write down the mean longitudes of the Sun in integer degrees, in consecutive steps of 1°, for a full circle of 360°. Lewis starts with the value of Aquarius 18° with the aim to quickly find the "beginning of the addition", which according to al-Battānī is around this mean solar longitude.
2. For each value of mean longitude of the Sun, determine the mean solar anomaly by subtracting the solar apogee. Lewis explicitly sets the solar apogee to be in Cancer 1° (91°). By deliberately choosing an integer value for the solar apogee, and thus rounding the proper value for 1485, Lewis can limit himself to obtain the solar anomaly in integer degrees. He thereby cleverly liberates himself from performing linear interpolation in the table of the equation of the Sun that follows in the next step.

150 These are the values for Capricornus 20° and Aquarius 27°, identical to the final table for the equation of time. Apparently, the scribe failed to copy the seconds-term for Virgo 17° as can be readily inferred from the corresponding value in hours of time.

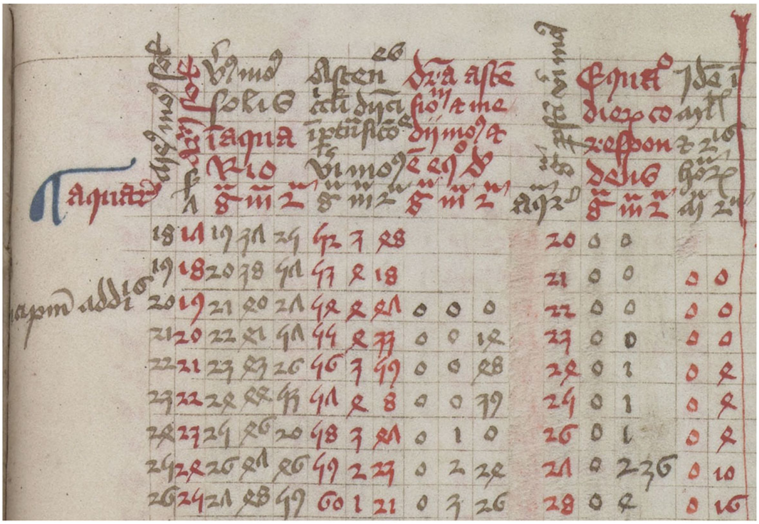

Fig. 3 Section from Lewis's table with intermediate results for the computation of the equation of time. The British Library, Add MS 89442, p. 119

3. With the solar anomaly, enter a table of the equation of the Sun and determine the true longitude of the Sun by subtracting (anomaly < 180°) or adding (anomaly > 180°) the solar equation from or to the integer mean longitude of the Sun. In Lewis's case the resulting true position of the Sun is now given to seconds, according to the precision of the solar equation he used.
4. Determine the right ascension of the true solar longitude by linear interpolation in a table for right ascension. Lewis gives the result of the interpolation to seconds.

   - From the values of right ascension of the true Sun in column 4, consider the difference between consecutive rows in the intermediate table and find the difference in right ascension that is the closest to the assumed progress in mean solar motion. Lewis worked with an increase of mean solar motion of 1° and, therefore, seeks the difference between right ascensions closest to 1°. In Lewis's case, this value is found when the mean Sun progresses from Aquarius 20° to Aquarius 21°. The corresponding difference between right ascensions of the true Sun then amounts to 0;59,46°. At this point the progress of the mean Sun is approximately identical to the increase of right ascension of the true Sun. Therefore, the mean solar day will be equal in length with the apparent solar day, and therefore, the equation of time is identically zero. If this point is chosen as the radix for the equation of time, the latter will always be additive. In the margin of his table with intermediate results, therefore, Lewis marks this point, when the mean Sun is in Aquarius 20°, as the "beginning of the addition." He thereby defines that at this point the difference between the increase in right ascension of the true Sun and the mean Sun is zero, and writes the value 0;0,0 in the fifth column of his table, as can be seen in Fig. 3. Note that this is a definition and also the reason why there are no values given in the fifth column for the first two rows. These two degrees, therefore, will reappear at the end of the intermediate table.

5. Starting from the radix obtained in the previous step, determine the difference between the mean longitude under consideration and the mean longitude of the radix. Add this difference to the right ascension of the true Sun at the radix. Subtract from this value the right ascension of the true Sun under consideration. The resulting value is written into the fifth column. Let us give an explicit example: when the mean Sun is at Aquarius 21° the right ascension of the true Sun is $55; 4,\ 33°$. For the point under consideration the mean Sun has advanced by 1° from the mean Sun at the radix. We, therefore, add 1° to the right ascension of the true Sun at the radix and obtain $54; 4,\ 47° + 1° = 55; 4,\ 47°$. From this value we subtract the right ascension of the true Sun under consideration to obtain $55; 4,\ 47° - 55; 4,\ 33° = 0; 0,\ 14°$. This value is exactly given in Lewis's intermediate table (see Fig. 3). Note that this step literally corresponds to the geometrical meaning of the equation of time. At this stage, after performing the step for the entire circle, we have already obtained an equation of time, though for unequally spaced, fractional values of longitude of the true Sun: for the position of the true Sun given in the third column the equation of time is given in the fifth column.
6. Consecutively write the integer degree of the true Sun that lies in the interval spanned by the value of the true Sun under consideration and the following row into the sixth column. Note that, due to the nature of the solar equation, there will be a few intervals that contain no or two integer degrees. The sixth column will, therefore, be shifted compared to the previous five columns.
7. For the integer degree of the true Sun in the sixth column, interpolate between the two corresponding true positions of the Sun in the third column and the corresponding values for the equation of time in the fifth column. Write the corresponding equation of time in time-degree in the seventh column.
8. Multiply the equation of time given in time-degrees from the seventh column by four and write the result in minutes and seconds of the hour in the eighth column.

Conceptually, Lewis's algorithm on how to derive a table for the equation of time is entirely different from the modern equation in formula (1). While the modern equation includes the solar equation $q(\lambda)$ as function of true anomaly, Lewis is working with a regular table for the equation of the Sun $\overline{q}\left(\overline{\lambda}\right)$ that is given for mean anomaly and which is readily found in sets of astronomical tables. Furthermore, Lewis does not add right ascension, as proposed by the modern formula (1), but determines the right ascensions of the true Sun. Finally, the epoch constant which assures positivity of the equation of time, is not an additive constant in Lewis's case but rather corresponds to a specific point on the sphere from which he starts his derivation—strictly speaking it is an artifact of the modern functional approach. Nevertheless, from a modern mathematical point of view, both approaches are identical, and therefore, the modern formula can still reliably capture the underlying parameters in a non-linear least squares fit. Lewis, yet, did not work with any parameters but with other tables. He captured the geometrical solution to the astronomical problem in such a way that he could use already existing tables for sub-problems. He did not recompute the solar equation, or right ascension, but used the tables that he had in his toolbox of astronomical tables. If we want to understand the mathematical practices of historical actors and groups and the transmission of these practices, we have to focus on their computational scenarios and the corresponding tabular practices. A modern mathematical formula might still be useful to identify parameter-estimates, but may not tell us anything about the details of mathematical practice and their transmission[151].

To further elucidate the latter statement, we have implemented Lewis's algorithm in a computer algebra system.[152] Our implementation is based on looking up values in other sub-tables and computation in sexagesimal arithmetic. Note, that Lewis is basically presenting his entire algorithm in his computational table, but there are a few subtle facts, related to intermediate rounding and precision that are not readily inferred from his table and can only be revealed upon proper recomputation and basic statistics. In turns out that Lewis employed standard rounding for sexagesimal numbers and computed to seconds, subsequently rounded to minutes for his equation of time in degrees.[153] Furthermore, for the recomputation we need to provide specific tables for the solar equation and right ascension. Thanks to the modern parameter-estimate, we know that the table of the solar equation employed by Lewis originates from the Parisian Alfonsine Tables and the table for right ascensions is based on al-Battānī's value for the obliquity. Nevertheless, we need to specify certain readings for these tables, preferably from the intellectual surroundings of Lewis or from manuscripts he owned or had access to.

From the organization and layout of the computational intermediate table we can easily reconstruct the solar equation used by Lewis by simply subtracting or adding the mean motion from the true position of the Sun. Since the computational table covers the whole circle of 360°, we can reconstruct the entire solar equation used by Lewis twice, independently of each other. The result of this double-reconstruction is very stable: between the two tables of the solar equation reconstructed from addition and subtraction, respectively, there are only three differences for the 180 values in total:

1. In the table that results from addition, the solar equation for 22° longitude wrongly reads 0;46,56° instead of the correct value 0;46,55°. Most likely this is a copying error of mistaking 6 for 5.
2. In the table that results from subtraction, the solar equation for 126° longitude wrongly reads 1;47,45° instead of the more common value 1;47,46°. Most likely this is a copying error of mistaking 5 for 6.
3. In the table that results from addition, the solar equation for 143° longitude wrongly reads 1;19,20° instead of the correct value 1;20,40°. Most likely this is a scribal error.

We explicate these details here, to highlight that Lewis most likely did not make a single computational error in adding or subtracting the solar equation from the mean Sun.[154] The three differences in the table are rather copying and scribal errors.

[151] For an example of the consequences of different computational scenarios in relation to Gerard of Cremona's translation of the *Almagest*, see Zieme (2023).

[152] We again chose *Mathematica*, but any other system may serve the same purpose.

[153] As noted above, in 3 out of 360 cases, Lewis also determined the value for the equation of time to seconds.

[154] Lewis often complains about scribal errors. For instance, he justifies the elaboration of his table of proportions (*tabula minutorum proportionalium*) as the original table of proportions to which he had access

Nevertheless, we do not intend to use the reconstructed table for our recomputation, but will only work with variant readings of the Alfonsine solar equation found in other, extant manuscripts in order to test dependencies on variant readings of tables—a circumstance to which modern recomputation is entirely blind.

What we will use instead, as a guiding principle, is the layout in which Lewis presents his solar equation in his intermediate table. From the second column for the argument, we readily infer that the table for the solar equation that he is using is organized in signs of 30° consecutively numbered from 0, 1, …, 11 with individual degrees from 0, 1, 2, …, 29. This layout is the same as employed by John of Lignères and found in his *Tables of 1322* and his *Tabule Magne*.[155] The same layout of the table is found in the manuscript Cambridge, Gonville and Caius College MS 110/179, p. 16, containing the *Tabule Magne*, which was owned by Roger Marchal (d. 1477), who, like Lewis, was also a fifteenth century Cambridge physician.[156] Therefore, we have included the solar equation table from the manuscript formerly owned by Marchal in our analysis, because both men might have acquired manuscript copies of the same sources during their education or professional career.[157]

Concerning the table of right ascension based on al-Battānī's value for the obliquity, used by Lewis for his computation, we can only infer that he used a table of normed right ascension. This is immediately clear from any of the entries from his fourth column, which are all off by about 90° from the true Sun (*cf.* Figure 3).

With respect to these boundary conditions, we have compiled a selection of variant readings for the tables of the Alfonsine solar equation and for al-Battānī's normed right ascension that circulated in Lewis's intellectual surroundings and which we used in our implementation of his algorithm. The result is summarized in Table 3.

A few comments are in order. Across the variant readings of the Alfonsine solar equation that we used in Lewis's algorithm the fitting results are almost stable and the number of values exactly reproduced in comparison to Lewis's table for the equation of time is almost constant (rows in Table 3). The six individual variant tables for the Alfonsine solar equation, though, without reproducing them here, contain between 5 and 16 scribal errors when compared among themselves. Since the solar equation is used twice to cover the full circle of 360°, on which the equation of time is build, twice the number of these scribal errors, i.e., between 10 and 32, enter the algorithm. These scribal variants are not visible in the final result, because they are of the order of seconds. The equation of time, however, originates from a difference in right ascension

Footnote 154 continued
was corrupted because of scribal errors (*BLa,* p. 44): 'Quia repperi tabulam proportionis que dicitur tabula minutorum proportionalium seu portiones longitudinum vicio scriptorum corrumptam, nec a principio satis praeter certificatam. In mente decrevi novam tabulam componere', a similar complaint may be found in his notebook, where he blames the scribes for having corrupted an eclipse table because of their lack of understanding: (*CUL*, fol. 146r): 'Nota etiam quod istud exemplum sequens de compositione tabularum eclipsis est corruptus scriptoribus non intelligentibus'.

155 On these two related sets of tables see, Chabás (2019), 175–206. On the *Tables of 1322* see, Chabás, Saby (2022).

156 James (1907/8), 1:114–15. Voigts (1995). The manuscript also contains the ephemerides for 1336–80 by John of Saxony and, therefore, we date it to the middle of the fourteenth century. On John of Saxony's ephemerides see, Chabás, Goldstein (2019). For a mathematical analysis of the ephemerides, see Kremer (2024).

157 In fact, MS BL, Egerton 889 was also annotated by Roger Marchal.

Table 3 Final results of the implementation of Lewis's algorithm when using existing variant readings from different manuscripts for the table of the Alfonsine solar equation (columns) and for al-Battānī's normed right ascension table (rows)

		Solar equations					
		A, 66r	E_1, 132r	E_2, 43v	E_2, 90v	E_2, 115r	*G*, p. 16
Right ascensions	*A*, 74v	9	9	9	9	9	8
	E_1, 142v	32	31	31	33	31	31
	E_2, 33r	324	321	323	323	324	321
	E_2, 118v	10	10	9	10	10	8
	E_2, 148v	9	9	9	9	9	8
	H, 163r	334	331	332	333	*334*	331

The numbers given in the table denote the number of values, out of 360 in total, that are exactly reproduced when compared to Lewis's final table for the equation of time given in minutes and seconds of time. The residuals for the values that do not match are of order + 4s

The best fit value (italics) is obtained for the combination H and E2

of the true Sun that is obtained from a table of right ascension given in degrees and minutes only. Therefore, scribal variants of the Alfonsine solar equation are almost invisible in the final result for the equation of time. The final result of the algorithm predominantly depends on variant readings of al-Battānī's table of right ascension.

The six variant readings of al-Battānī's table of right ascension that we used differ up to 10% in their 360 values in total but the consequences for the table of the equation of time are drastic (columns in Table 3). Clearly, when using the tables of right ascension in *H* (fol. 163r) and E_2 (fol. 33r) we can almost reproduce all the values of Lewis's table exactly. While the remaining four variant readings of the table of right ascension reproduce almost none of Lewis's results. Since all the six tables of right ascension we used are unmistakably identified as al-Battānī's table this phenomenon needs further clarification. The explanation is simply that there are two stable variant readings of al-Battānī's table of right ascension that were transmitted and disseminated independently of each other. These two variants differ by a line-slip that results in a shift of an entire block of 12 values from Aquarius 16°–27° and, coherently by symmetry, from Leo 16°–27°.[158] Right ascension, however, has a symmetry to the equinoxes and solstices and, therefore, the block-shift, when comparing both variants, should appear four times and not only twice. We thus conclude that the variant witnessed in *A* (fols. 74v–75r), E_1 (fols. 142v–143v), E_2 (fol. 118v), and E_2 (fols. 148v–149r) mostly likely originates from an early scribal error that later underwent an attempted fix by symmetry, yet only half of the symmetry relations, i.e., ignoring the anti-symmetry around the solstices, were employed. We denote this variant as variant *B*. The variant witnessed in *H* (fol. 163r) and E_2 (fol. 33r), which we denote as variant *A*, is the proper one and also found

[158] For a similar example of such a block-shift, see Kremer (2021). Kremer calls this error a "column slippage". We choose a different nomenclature here, to indicate that the variant has a stable history of transmission.

Table 4 Block-shift (italics) in Aquarius that appears in the variant readings of al-Battānī's table of (normed) right ascension

deg	Variant *A*		Variant *B*	
	H, 163r		E_2, 118v	
	deg	min	deg	min
315	47	30	47	30
316	48	30	48	*29*
317	49	*29*	49	*28*
318	50	*28*	50	*27*
319	51	*27*	51	*26*
320	52	*26*	52	*25*
321	53	*25*	53	*24*
322	54	*24*	54	*22*
323	55	*22*	55	*20*
324	56	*20*	56	*18*
325	57	*19*	57	*16*
326	58	*17*	58	*14*
327	59	*14*	59	13
328	60	12	60	12

The block-shift also appears in Leo and, therefore, is not a random scribal error but a stable, transmitted variant

in most manuscript witnesses of the Toledan Tables.[159] Nevertheless, both variants *A* and *B* appear to be transmitted stably and are found in several manuscripts across Europe. We illustrate this block-shift in Aquarius in Table 4, where we transcribe an excerpt from two representative witnesses for variants *A* and *B*.

To conclude our discussion on the dependence of the table of the equation of time on the two variants *A* and *B* of al-Battānī's table for right ascension, we note that the radix of Lewis's algorithm, i.e., the beginning of the addition on which the whole table rests, occurs when the true Sun is between Aquarius 21°–22° (Aquarius 20° of mean solar longitude in Fig. 3). This radix is right in the middle of the shifted block of variant *B* of al-Battānī's table for right ascension and thus off by about 1 min (see Table 4). Because all subsequent values are compared to this radix, the entire resulting table for the equation of time is shifted by 1 min in time-degrees, or 4 s in hours of time, and almost none of the final values are exactly reproduced compared to Lewis.

The best fit result is achieved when we use the Alfonsine solar equation found in E_2, fol. 115r, and al-Battānī's table for normed right ascension from *H*, fol. 163r. It appears very likely that Lewis had direct access to these two manuscripts. *H* was formerly owned by Simon Bredon and contains a table of contents in his hand. As we argued above, from statistical analysis we may not discriminate between different readings of the Alfonsine solar equation. Nevertheless, the layout of the table for the

159 Pedersen (2002), 3:968–75.

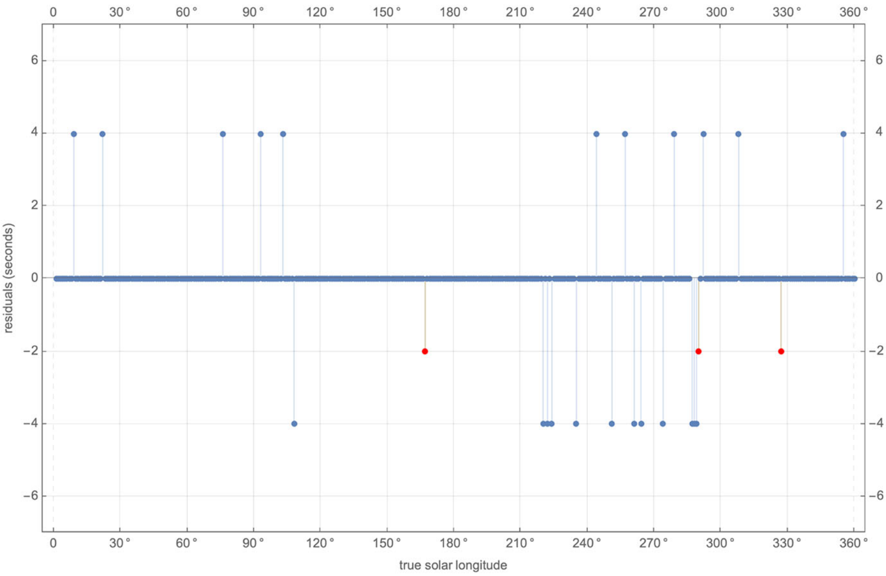

Fig. 4 Residuals of Lewis's table for the equation of time, given in hours of time, compared to our historical recomputation using Lewis's algorithm and the Alfonsine solar equation from E_2, 115r and al-Battānī's table for normed right ascension from H, 163r. The three red data-points correspond to the values for 167°, 290°, and 327° for which Lewis used an increased precision but which we did not treat separately

solar equation in E_2, fol. 115r is almost identical to the structure found in Lewis's intermediate table. The signs are numbered from 0, 1, …, 11 and, thus, contain 30° each. However, the degrees per sign are consecutively numbered from 1, …, 30 and not from 0, 1, …, 29 as is the case for the intermediate table. In addition, we argue that Lewis very likely had direct access to the manuscript E_2. We, therefore, conclude that Lewis likely consulted these two manuscripts when he derived his table of the equation of time. However, another hypothesis is that he could have copied and owned a set of tables that derive from these two manuscripts and, thus, originate from the intellectual surrounding of Simon Bredon. The residuals for the best fit result, where we subtracted our historical recomputation from Lewis's final table in minutes and seconds of time is given in Fig. 4. Out of 360 values in total we reproduced 334 exactly. Three values are off by − 2 s. These values were computed with higher precision by Lewis and he performed the final linear interpolation to seconds. We did not treat these three cases separately, but could simply have increased precision in our algorithm for the last linear interpolation. Eventually, 23 values are off by ± 4 s, which represents the minimal possible deviation. Most likely these deviations result from slightly different linear interpolations by Lewis or from another few random scribal errors in the table of right ascension used by Lewis. In summary our historical implementation reproduced about 94% values exactly.

7 Conclusion

The purpose of this article is to present a comprehensive analysis of the life and astronomical work of Lewis Caerleon, including the first examination of *BLa* and the edition of his work on the equation of time. Lewis Caerleon worked out a whole programme for calculating eclipses. This can be reconstructed from various manuscripts that he copied and commissioned. Regarding the new evidence we have discovered, we hope that the discussion has clearly demonstrated the sources and methodology of this meticulous calculator. From the various strands of evidence related to his life that we discovered, we can conclude that Lewis was at Clare College during his time in Cambridge before presumably moving to Oxford. While at Merton College, he had access to various sources, including Richard of Wallingford, Simon Bredon, and John Killigworth, along with some lesser-known scholars like John Curteys and Walter Hertt. From his notebook, we can trace the beginning of his astronomical work in 1481 when he elaborated new material on the basis of John Curteys's tables. During this time, he also developed a geometrical method for eclipse computation and computed a table for finding the time of true syzygies. As he would do later with other sets of tables, he applied his *nove tabule expanse* to the solar eclipse of 28 May 1481, which he had calculated. The thorough examination of three manuscripts overseen and commissioned by Lewis after 1485, which feature only his work, reveals he developed his eclipse computation programme in 1482, coinciding with the creation of eclipse and parallax tables along with their canons. The two manuscripts provide evidence of this pursuit by Lewis during his alleged captivity in the Tower of London in 1485. From the new evidence gleaned in manuscripts commissioned or owned by Lewis, it can be concluded that his astronomical production was concentrated between 1481 and 1485, with the majority of his work completed in 1482/1483. During that time, he produced different sets of tables in London but for the latitude of Cambridge.

However, from *BLa* which may be considered as Lewis's *Opera omnia* we aimed to illustrate the scope of his astronomical practice and methodology. This unique manuscript encompasses a broader portion of Lewis's work, comprising spherical astronomy (*primum mobile*), trigonometry, predictions of eclipses, and the equation of time designed for the same goal of calculating eclipses. It is this manuscript that fills the gap in our knowledge of the scientific output of this astronomer. A significant amount of this work is only in *BLa*, including the material on the equation of time. This volume illustrates that Lewis based his work on various *auctoritates,* primarily Simon Bredon and Richard of Wallingford, and used their works as sources. The equation of time supports this connection to Simon Bredon, and indirectly to the *Almagest minor*. It is probable that Lewis had access to Simon's manuscripts, or texts closely related to them. The equation of time material collected by Lewis was, therefore, based entirely on Simon Bredon's instructions in his commentary, Book III, 24. It appears that Lewis employed a comparable method with his other pieces of work, such as his tables of right and oblique ascensions and his tables of eclipses. He persistently revised existing writings and enhanced them.

Despite mainly referring to other sources, the work of Lewis Caerleon is well in line with the Alfonsine corpus of mathematical astronomy.[160] Although there are several later variants of astronomical tables derived from the Alfonsine Tables, the underlying geometrical models and especially their parameters remained unchanged with regard to the motion of the planets and luminaries. Beyond planetary motion, however, innovations are rather to be found in spherical astronomy. For example, some early modern astronomers updated their maximum value of solar declination, i.e., obliquity of the ecliptic, and with it derived new tables of right and oblique ascension, as Lewis did as well.[161] Especially, in regard to the dissemination of Alfonsine material to more northern latitudes, the derivation of new tables of oblique ascensions for such latitudes was necessary, mainly for the application of astronomical tables in astrological matters or simply to determine the length of daylight. A similar role, as we have argued above, is played by the equation of time, which was essential for eclipse computations. The table of the equation of time needed to be newly computed, not because of the dissemination of astronomical tables through space to other latitudes, but because of the dissemination through time: the equation of time, crucially depends on the position of the solar apogee, and, therefore, needed to be newly computed as the centuries passed and the solar apogee progressed.

As opposed to the rich landscape of different parameters in Islamicate astronomy, reflected by the vast number of different *zījes*, medieval Latin astronomical tables are rather stable with regard to their underlying parameters.[162] Therefore, it is of major importance to study closely those tables in Latin astronomy that were newly computed. The underlying sources and mathematical practices employed in the corresponding derivations will most likely lead to new insights in the transmission of knowledge. In this article we have exemplified this approach through Lewis Caerleon's work on the equation of time. By closely analyzing the details of his calculational scenario of how he derived his table for the equation of time step by step, adopting the historical scheme of sexagesimal arithmetic, we were able to determine the sources that he used and identify the variants of the sub-tables, if not even the very manuscripts themselves, consulted by Lewis. We believe that this is a new and promising approach in the historiography of mathematical astronomy that reaches far beyond usual modern mathematical analyses, with a sole focus on parameters, because it allows for a much more refined analysis of the exchange and transmission of knowledge and historical practices.[163]

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[160] On the Alfonsine Tables, see Poulle (1988). On the Alfonsine corpus, see Chabás, Goldstein (2003). For a recent study of material from the Alfonsine corpus, see Kremer, Husson, Chabás (2022).

[161] For some examples of different values of the obliquity, as well as right and oblique ascension tables and other related quantities, see Chabás, Goldstein (2012), 19–36.

[162] For a survey of *zījes*, see Kennedy (1956). See also King and Samsó (2001).

[163] For an overview on current practices of tabular analysis, see Husson, Montelle, van Dalen (2021).

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Data availability The data sets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

Appendix A. Lewis Caerleon's canons for the equation of time

The following text is based on the only witness, *BLa,* displaying the Lewis Caerleon's canons for the equation of time. We followed the reading of the manuscript, although the punctuation is ours.

Latin text, *BLa,* p. 118

Novum opus

Quia tabula communis equationis dierum quam composuit Azarchel nunc propter lapsum temporis transit in errorem propter longinquam remotionem augis Solis, ideo, mecum decrevi novam tabulam componere.

Circa quod est notandum quod equatio dierum est differentia inter dies mediocres seu equales et dies differentes vel inequales. Dies enim mediocris seu medius vel equalis semper et precise continet .24. horas equales, ut supponunt omnes astronomi in suis calculis. Et iste dies supponit tam motum Solis quam etiam ascensiones circuli directi fore semper equales, quod non est verum.

Dies vero differens et inequalis est tempus integre revolutionis cum eo quod Sol interim vero motu pertransivit. Ille vero dies, scilicet, differens est inequalis duplici de causa, scilicet propter inequalitatem veri motus Solis, et propter inequalitatem ascensionem eiusdem veri motus.

Differentia vero proveniens ex utraque causa inequalitatis Solis inter diem mediocrem et differentem dicitur equatio dierum que licet parva sit in uno die crescit tunc usque ad 8 gradus et amplius.

Et ut dicit Ptholomeus, differentia maxima ex utraque causa inequalitatis est 8 gradus et tertia pars unius gradus. Nam ut dicit maxima differentia simpliciter ex inequalitate motus Solis est 3 gradus et due tertie unius gradus, et maxima differentia ex inequalitate ascensionum proveniens est ut ipse dicit 4 gradus et due tertie.

Nos tamen moderni invenimus maximam differentiam simpliciter, ex inequalitate veri motus Solis provenientem 4 gradus et unam tertiam fere, quod patet si subtrahatur verus motus Solis a principio Arietis usque ad principium Libre de medio motu Solis pro eodem tempore.

Et invenimus maximam differentiam ex inequalitate ascensionum circuli directi provenientem simpliciter 5 gradus, ut patet si subtrahantur ascensiones circuli directi que sunt a 16 Aquarii usque ad 16 Tauri, quia tunc remanebunt 85 gradus in illis vero signis, est principium et finis diminutionis ascensionum circuli directi ex hoc sequitur quod tota differentia possibilis est[164] ex utraque causa inequalitatis simul potest esse 9 gradus et una 3a.

Non tamen oportet, nec est verum, omnes dies differentes minores per tantum excedi a tot diebus mediis, scilicet, per aggregatum ex magnis differentis causarum ambarum. Quia non in eodem loco quo est maxima differentia ex altera causa est maxima differentia ex reliqua, nec ab eodem puncto incipiunt additiones vel diminutiones unius cause et alterius.

Ymo altera causa incipit minuere antequam reliqua ad maximam sue augmentationis devenerit propter motum augis. Et ideo, non semper invenitur maxima equatio dierum seu differentia ex ambabus causis simul una et eadem et equaliter propter variationem augis Solis, ut patet in tabulis. Quia Azarchel invenit maximam differentiam ex utraque causa simul in tempore suo 7 gradus et 54 minuta, Albategni vero 7 gradus et 57 minuta, ego vero in diebus meis supponendo augem Solis in primo gradu Cancri perfecto inveni maximam differentiam ex utraque causa simul 8 gradus, 12 minuta et 30 secunda, precise operando quod est prope positionem Ptholomei.

Ista vero tabula a diversitate diversimode componitur, ut patet per Ptholomeum, Albategni et Bredon libro suo 2° super Almagestum, qui tradit ibidem doctrinam completam de ea.

Ego vero ponam unum modum lenem per quem precissime fieri potest tabula equationis dierum, ut ego feci qualicet[165] vero poterit esse perpetua, operando tamen cum ea per 100 vel 200 annos, insensibilis erit error.

Pro quo, nota quod dies medius seu mediocris presupponunt tam motum Solis quam ascensiones circuli directi esse semper equales, quod non est verum, dies vero differens supponit econtra quod est verum.

Ut ergo invenias precise differentiam inter diem mediocrem et differentem ex utraque causa simul proveniente, suppone Solem secundum medium cursum in 18 gradu Aquarii, eo quod a principio illius gradus secundum verum motum incipit dies differens esse minor die mediocri ex causa inequalitatis ascensionum, ut patet in tabulis ascensionum circuli directi.

Et ab illo gradu, scribe singillatim gradu per gradum medium motum Solis usque ad completam revolutionem. Suppone etiam augem Solis esse in aliquo gradu determinato perfecto, quam subtrahe de medio motu et proveniet argumentum Solis, quod etiam scribe in directo medii motus usque ad completam revolutionem.

[164] *del.*

[165] The manuscript reads ‘qualicet’ to which the scribe seems to have given the meaning of ‘qualiter’. We are grateful to Peter Jones for pointing out this spelling of the manuscript.

Deinde cum argumento Solis nunc invento, intra tabulam equationis Solis et equa motum Solis usque ad completam revolutionem, et scribe etiam verum motum Solis in tertio loco in directo medii motus usque ad completam revolutionem.

Deinde subtrahe verum motum Solis primo inventum de vero motu Solis secundo invento vel equato, et remanebit arcus veri motus Solis in pertransitione unius gradus medii motus cuius arcus veri motus. Quere ascensionem in circulo directo signi et gradus veri motus Solis, que si sit unus gradus precise erit ibidem quantitas diei differentis equalis quantitati diei mediocris et ideo erit ibidem inceptio additionis et ideo ponuntur illi cifra in directo illius gradus Aquarii veri motus.

Si vero illa ascensio fuerit maior uno gradu, inquiratur ascensio veri motus Solis correspondentis pertransitioni gradus subsequentis medii motus, nec cesses consequensque deveneris ad ascensionem arcus veri motus que precise continet unium gradum, ut ibidem additionis principium habetur.

Illo igitur gradu invento inquiratur verus motus Solis correspondens pertransitioni duorum graduum coniunctioni illius, scilicet, et gradus subsequentis et illius veri motus ascensione a duobus gradibus, subtracta ponatur differentia in directo gradus subsequentis.

Deinde invento vero motu Solis correspondente pertransitioni 3 graduum simul iunctorum scilicet duorum predictorum et tertii subsequentis subtrahatur eius ascensio a tribus gradibus medii motus et ponatur differentia contra gradum tertium subsequentem, et per istum modum procedas ulterius usque ad totius circuli complementum.

Hoc completo, ut scias equationem dierum correspondentem precise cuiuslibet gradui perfecto veri motus, accipe partem proportionalem, secundum communem modum quam addes vel minues secundum exigentiam loci, et productum scribe in tabula in directo gradus perfecti veri motus Solis. Quia cum gradu veri motus Solis semper est intrandum in tabula equationis dierum et sic patet complete compositio antedicte tabule.

Si igitur radices motuum posite fuerint super principium additionis in tabula, scilicet, veri dies medii incipiunt esse maiores diebus differentibus, scilicet, in predicto gradu Aquarii tunc differentia quelibet ibi inventa addenda est continue, ut dies differentes ex diebus mediis habentur.

Si tamen ponerentur radices super principium diminutionis tunc esset differentia quelibet inventa in tabula numeranda de diebus mediis.

Et nota quod hec tabula deservit omni regioni et omni orizonti, si dies incipiatur a meridie vel a media nocte. Sed si dies inciperetur ab ortu Solis vel occasu vel a quacumque alia hora, tunc pro omni orizonte oportet habere propriam tabulam equationis dierum, et hoc accidit propter variationem inequalitatis ascensionum in circulo obliquo in omnium orizonte differentium. Et propter hoc, omnes astronomi incipiunt diem a meridie quia ascensiones circuli directi sunt eed et equales in omni latitudine et orizonte.

Si vero cupis habere latiorem tractatum de ista materia, vide Ptholomeum, Albategni, Gebir et Bredon. Sed Bredon in fine libri sui secundi super Almagestum comprehendit sententias omnium illorum et ponit ibi modum meum hic prescriptum in virtute, quamvis non ita plane, et ibi tradit doctrinam completam et perfectam de equatione dierum. Sed hoc ad presens sufficiat.

Translation

New work

For the common table of the equation of time that Azarchel composed, is now in error due to the time elapsed and the long displacement of the solar apogee. Therefore, I decided to compose a new table.

About that it must be noted that the equation of time is the difference between the mean days or equal days and the apparent days or unequal days. Indeed, the average, or mean or equal day always and precisely contains 24 equal hours, as all the astronomers assume in their computations. And that [mean] day supposes that both the solar motion and the right ascension are always equal, but that is not true.

The apparent or unequal day is truly the time of complete revolution which the Sun in motion travelled through. This day, of course, is different and unequal for two reasons, because of the inequality of the solar motion [solar equation], and because of the inequality of the ascension of the true motion [right ascension].

In truth, the difference originating from both causes of the inequality of the Sun, between the mean day and the apparent day is called the equation of time, although it may be small in one day and then increases up to eight degrees and more.

And as Ptolemy says, the maximum difference from both causes of inequality is eight degrees and a third of degree.[166] For as he says, the greatest difference from the inequality of the solar motion [solar anomaly] is simply three degrees and two thirds of one degree, and the greatest difference from the inequality of the ascension [variation at the time of meridian-crossing] is said of four degrees and two thirds.

However, we, the moderns, find the maximum difference simply from the inequality of the solar motion resulting in four degrees and one third, which is clear if the true solar motion from the beginning of Aries until the beginning of Libra is subtracted from the mean motion of the Sun for the same time.

And we find the maximum difference from the inequality of the right ascension simply resulting in five degrees, as it appears if the right ascensions, that are from 16 Aquarius to 16 Taurus, are subtracted. For 85 degrees will then certainly remain in these signs, it is the beginning and the end of the subtraction of the right ascensions. From this follows that the entire possible difference from the two causes of inequality can also be nine degrees and one third.

However, it is not necessary, nor is it true, that all the smallest apparent days are so much exceeded by so many mean days, that is to say, by the addition of the maximum differences of both causes. For the maximum difference from the other cause is not in the same place as the maximum difference from the other one [other cause], nor do the subtractions or additions of one cause and the other begin from the same point.

On the contrary, the other cause starts to decrease before the other reaches its maximum augmentation due to the motion of the apogee. In addition, therefore, it is not always found that the maximum equation of time or the difference from both causes is simultaneously one and the same and equal because of the variation of the solar apogee, as it appears in the tables. For Azarchel, in his time, found the maximum difference from both causes at the same time 7 degrees and 54 min, Albategni, however, 7 degrees and 57 min and myself, in my time, assuming that the solar apogee was in

[166] Cf. Ptolemy's *Almagest,* III.9; Toomer (1984),171.

the first degree of Cancer, I found the maximum difference from both causes at the same time: 8 degrees, 12 min and 30 s, operating as close as possible to Ptolemy's position.

This table of a different kind was composed as it appears in Ptolemy, Albategni and Bredon, in his 2nd book on the *Almagest,* who transmits there the same complete doctrine.

I truly present a gentle method with which one can very precisely make a table of the equation of time, as I have made myself in such manner as it could be perpetual, yet operating with it for 100 or 200 years, the error will be insensible.

For this, note that the average or mean days implies that both the solar motion and the right ascensions are always equals, which is not true, but the apparent day supposes on the contrary that it is true.

Thus, you will find precisely the difference between the mean day and the apparent day arising from both causes at the same time. Assume the Sun to be in its mean motion at 18 degrees Aquarius, because from the beginning of that degree point according to its true motion, the apparent day begins to be smaller than the mean day due to the inequality of ascension, as it appears in the table of right ascensions.

And from this degree, write one after the other, degree per degree the mean motion of the Sun until a complete revolution. Assume also that the solar apogee is in some determined complete degree, then subtract it from the mean motion and the result will be the argument of the Sun, [solar anomaly] that you also write in front of the mean motion until the complete revolution.

Then, with the argument of the Sun [solar anomaly] now found, enter in the table of the equation of the Sun and compute the solar motion up to the complete revolution, and also write the true solar motion in the third position in front of the mean motion up to the complete revolution.

Then, subtract the true solar motion first found from the true solar motion secondly found and equated, there will remain the arc of the true solar motion passing through one degree of the mean motion of this arc of true motion. Seek the right ascension of the sign and degree of the true solar motion, that if there is one precise degree there will be an equal amount of apparent and mean days, and therefore, the beginning of the addition will be there, and therefore, the numbers will be placed in front of that degree of Aquarius of the true motion.

If this ascension was greater than a degree, the ascension of the true solar motion corresponding to the crossing of the subsequent degree of the mean motion must be sought. Do not cease and you will arrive to the ascension of the arc of the true motion that contains precisely one degree, thus in the same time, as the beginning of the addition will start there.

Therefore, having found that degree, the true solar motion corresponding to the crossing of those two degrees in conjunction of this degree, that is, the subsequent degree and that true motion in ascension from the two degrees is sought. The subtracted difference is placed in front of the subsequent degree.

Then, from the true solar motion corresponding to the crossing of three degrees altogether, that means, with the two preceding degrees, and the third subsequent one, its ascension is subtracted from the three degrees of the mean motion. The difference is placed against the third subsequent degree, and with this method, proceed further until the completion of the whole circle.

Once completed, as you know the exact equation of time corresponding to each complete degrees of the true motion, take the table of proportion (table of interpolation), that means, the general manner which you add or subtract according to the necessity of the position, and write the product in the table in front of the perfect [integer] degree of the true solar motion. For one always enters in the table of the equation of time with the degree of the true solar motion, and thus the complete composition of the aforementioned table is clear.

Therefore, if the radix of the motions were at the beginning of the addition in the table, that is, the true mean days begin to be greater than the apparent days, that is, in the aforesaid degree of Aquarius, so the difference found must be added continuously, so that the apparent days are given from the mean days.

Nevertheless, if the radices are placed at the beginning of the subtraction, then any difference found is in the table of mean days.

And note that this table covers every region and every horizon, if the day begins at midday or at midnight. But, if the day were to begin at sunrise or sunset, or from whatever hour, then a proper table of the equation of time is needed for each horizon, and this happens because of the variation of the inequality of the oblique ascension in all the different horizons. In addition, for this reason, all astronomers begin the day at midday for the right ascension is equal in every latitude and horizon.

However, if you want to have a more substantial treatise on this matter, see Ptolemy, Albategni, Gebir and Bredon. But, Bredon at the end of his second book on the *Almagest* covers the opinions of all of them, and there he placed my method, here presented in virtue, although not so clearly, and here, he transmits a complete and perfect doctrine of the equation of time. But this is enough for now.

Appendix B. Simon Bredon, *Commentum super Almagesti,* Book III. 22–24

Manuscripts used for the edition (sigla):

D_1 Oxford, Bodleian Library, Digby 168, fols. 37^{v}-39^{r}

D_2 Oxford, Bodleian Library, Digby 178, fols. 83^{v}-86^{r}[7]

Edition principles

The edition of Simon Bredon's commentary of Book III. 22–24 of the *Almagest* is based on the two only extant manuscripts, Oxford, Bodleian Library, Digby 168 (D_1) and Oxford, Bodleian Library, Digby 178 (D_2). The following text is mainly based on D_2 (Lewis Caerleon's copy) which contains a few variants compared to Simon Bredon's autograph copy, D_1. D_2 is indeed likely to belong to the same tradition as D_1, from which it was most likely copied directly, or from a direct copy of D_1.

For the edition, we generally follow D_2, except in a few cases where the latter omits a word or preposition otherwise included in D_1. Therefore, we include variants found in D_1 in the critical apparatus, and in some cases, D_2 variants are also listed in notes.

We have incorporated in only one case, at the end of III.23, an entire passage from *D_1,* originally written by Simon Bredon and then deleted by him, which Lewis Caerleon did not include in his copy, D_2. We have included it in the main text as it presents an interesting attempt by Simon Bredon to compose a perpetual table for the equation of time, an idea which he eventually abandoned in order to finally provide the rule for making a ‘non-perpetual’ table for the equation of time in III.24.

Folio numbers in the main text correspond to D_2. We specify the change in folio numbers in D_1 within the apparatus.

We report marginalia, interlinear glosses, deletions, and corrections systematically. Additionally, D_2 includes a couple of marginal glosses written by Lewis Caerleon to comment on Simon Bredon’s text. Some words are also superscripted by Lewis to correct an omission in D_2, as specified in the apparatus. D_1 was Simon Bredon’s working copy, with many passages added and then crossed out for deletion, while entire paragraphs were included in the margin with the help of *signes-de-renvoi*. The passages copied in the margins by Simon Bredon in D_1 are systematically included in D_2. Therefore, we specify in the apparatus whenever those passages are situated in the margin in D_1. Similarly, we have decided to mention in the apparatus every passage crossed out by Simon Bredon.

A certain number of spelling variants may be found in the two copies. We have decided to mention most of them in the apparatus. Punctuation is ours. However, the reader should be aware that we normalised some spellings and standardised some others.

The spelling variants we normalised are the following:

- in D_1 Ptolemy is spelled *Tholomeus,* we retained *Ptholomeus* as in D_2.
- ‘-ci’ in ‘-ti’ for *tercium/tertium* and *distancia/distantia*
- We include a ‘y’ when more common in modern spelling for *Egyptorum* instead of *Egiptorum.*
- We retained the absence of diphthong in both manuscripts, e.g. *equatio* and not *aequatio.*
- We kept the spelling found in both manuscripts of *coniunctio* instead of *conjunctio.*
- The numerical readings in the manuscript were closely followed, and Arabic numerals were used when provided. Discrepancies occurred when a witness included an Arabic numeral while the other provided a complete word, e.g.,: ‘duorum’ and ‘2^{orum}’. In that case, the reading in D_1 was chosen, and the D_2 variants were added to the apparatus.

Abbreviations in the apparatus

add	*additur*	Added
add. et del	*additur et deletur*	Words added and then deleted
marg	*margine*	Text or annotations written in the margin
supra lineam		Word(s) written above the line
iter. et del	*iteratur et deletur*	Word(s) given twice, one of them is then deleted

†…†	Uncertain words
< … >	Addition by the editor

[fol. 83v][167]

22. Locum quo incipit inequalitas dierum ex inequalitate ascensionum in circulo obliquo resultans, nec non et maximam differentiam inter dies differentes et medios in orizonte dato collectam scrutari. Unde in transitu medietatis orbis signorum per Arietem erunt dies medii diebus differentibus longiores per aliquid et in transitu alterius medietatis per Libram erunt ergo dies medii breviores differentibus per tantundem.

Accidit autem variatio loci qui queretur secundum quod climata variantur.[168] Est tamen in omni climate inter punctum inceptionis in circulo directo in prima quarta zodiaci et tropicum estivalem vel in puncto sibi opposito post tropicum yemalem, habentis ergo tabulis ascensionum pro orizonte dato inquiratur, ante tropicum estivalem, ubi invenitur in tabulis dies medius equalis diei differenti et erit ibidem, vel in puncto sibi opposito,[169] indifferenter inceptio,[170] inequalitatis[171] dierum ex proposita causa in orizonte dato resultans. Et in puncto inceptioni opposito erit finis Capitis ergo in dictis tabulis ascensionibus medietatis zodiaci inter puncta sicut[172] habita intercepta,[173] quantum ille ascensiones different[174] a medietate circuli 0 a 180 gradibus,[175] tantum different dies medii illius medietatis a differentibus diebus eiusdem, quod si indirecta medietate fuerit[176] signum Arietis, erunt per dictam differentiam dies medii diebus differentibus longiores et in medietate alia econverso[177] eo quod **[fol. 84r]** in medietate zodiaci in qua est signum Arietis subtrahuntur differentie ascensionum in circulo obliquo[178] ab ascensionibus in circulo directo,[179] et in alia medietate adduntur, ut patet in 20a coniunctione[180] secundi huius. Et ex hoc sequitur quod dies differentes medietatis zodiaci in qua est signum Libre exceduntur coniunctim dies differentes alterius medietatis per duplum differentie antedicte eo quod quantum dies differentes addunt super dies mediocres ex parte Libre tam ex parte Arietis minuuntur ab iisdem. Et

167 *D1* fol. 37v.

168 Nota quod istam inequalitatem dierum in circulo obliquo ponit propter illos qui incipiunt diem vernalem a Solis ortu vel occasu, et tunc nullus est respectus habendus ad circulum remanet, et apud eos qui incipiunt diem a meridie nullus erit rectus ad orizontem obliquitatem] *marg. per Ludowicum Caerleon, D2.*

169 incepte *add. et del. D1.*

170 die *add. et del. D1.*

171 de *add. et del. D1.*

172 sic *D2.*

173 intercepte *D2.*

174 differunt *D2.*

175 saltem a 180 gradibus *D1.*

176 Arietis *add. et del. D1.*

177 econverso] *iter. et del. D2* | non patet per 20am coniunctionem *add. et del. D1.*

178 obliquo] supra *add. et del. D1.*

179 non patet in 20a coniunctione *add. et del. D1.*

180 in] *om. D2.*

est notandum quod hec[181] differentia sic inventa in orizonte dato excedit differentiam maximi diei illius orizontis supra diem[182] equinoctialem que quidem differentiam, scilicet[183] maximi diei ad equinoctialem est excessus quo ascensio medietatis zodiaci a Cancro in Capricornum excedit .180. gradus.[184]

23. Cuiuscumque diei differentis ad diem medium[185] differentiam ex alterutra dictarum causarum vel ex ambabus simul causatam inquirere, necnon et locum quo inceptio additionis seu diminutionis ex ambabus simul causis contigerit assignare.

Ut si differentiam inter quemcumque diem differentem et medium ex inequalitate motus Solis causatam habere volueris invenias per 18am huius veros motus Solis tam pro primo oppositi illius diei quam pro ultimo[186] de quo queris. Deinde subtracto minore de maiore capiatur differentia que a die medio[187] subtrahenda est si sit minor vel subtrahendus est arcus diei medii ab ea si sit maior et reliquetur differentiam quam inquiris. Quod si differentiam ex inequalitate ascensionis causatam habere volueris, invento per 18am huius medio motu Solis et vero[188] pro principio et pro fine diei de quo queris et minori de maiore subtracto. Arcus residui inveniatur ascensio in spera recta per ultimam primi huius[189] si in linea meridionali dies inceperis[190] vel inquiritur illius arcus ascensio in spera obliqua per 19am secundi huius. Si ab oriente inceperis dies tuos, qua subtracta ab arcu diei mediocris si sit minor vel arcu diei medii subtracto ab ea si sit maior, resultabit differentiam de qua queris. Et est notandum quod in equationibus dierum, melius est operari cum diebus incipientibus a linea meridionali quam ab orizonte, cuius causam ponit Ptholomeus, eo quod diversitates que accidunt in diebus incipientibus ab orizonte, scilicet orizonta diversa, diversimode variantur. Sed diversitates que accidunt in diebus incoatis a linea meridionali in orizontibus singulis manent eedem. Si autem differentiam ex causis ambabus simul pervenientem habere volueris utriusque cause differentiam respectu diei de qua queris per doctrinam protractam inquire, et per tres coniunctiones premissas considera an utraque causam differentiam suam addat supra diem mediocrem vel utraque differentiam suam minuat aut addat **[fol. 84v]** altera reliqua minuente. Si autem ambe cause addant simul vel minuant. Differentie ambe diei de quo queris simul addantur et si una causa addat, et alia minuat, subtrahatur minor differentia de maiori, et resultabit differentia ex

[181] hec] *om. D*$_2$.

[182] equalem *add. et del. D*$_2$.

[183] scilicet] *om. D*$_2$.

[184] Est et notandum quod volueris etiam operari in equationibus dierum melius est operari cum diebus incipientibus a media nocte vel a meridie quam ab ortu Solis vel occasu, cuius causam ponit Tholomeus eo quod diversitates que accidunt in diebus incipientibus ab ortu vel occasu scilicet orizonta diversa diversimode variantur. Sed diversitates que in diebus incipientibus a medie nocte vel a meridie accidere in orizontibus singulis manent eedem *add. et del. D*$_1$.

[185] medium] seu quorumque dierum differentium ab tot medios *add. et del. D*$_1$.

[186] vel illorum differentium *add. et del. D*$_1$.

[187] vel a diebus mediis *add. et del. D*$_1$.

[188] et vero] *s.l. D*$_2$| *om. D*$_1$.

[189] per ultimam primi huius] *marg. D*$_1$.

[190] vel inque *add. add. et del. D*$_1$.

ambabus causis causata. Si vero quantum una differentia addit tam precise alia minuit, tunc ibi equalis erit dies differens diei mediocri.[191]

Si igitur in die sequenti addat utraque causa, vel altera plus addat quam reliqua minuat. Tunc ibi erit initium additionis. Si vero in die sequenti utraque causa minuat seu altera plus minuat quam reliqua addat. Tunc erit ibi principium diminutionis. Est tamen notandum quod licet iste sit unus modus inveniendi differentiam ex ambabus causis resultantem et modus etiam inveniendi principium additionis vel diminutionis. Non tamen est modus in toto precisus tum propter hoc quod ex isto modo operandi sequitur quod cuicumque differentie resultanti ex inequali motu Solis in ecentrico, correspondeat ascensio sibi equalis quod non est verum. Tum etiam propter hoc quod[192] arcus zodiaci[193] correspondens medio motui Solis pro principio diei[194] cuiuslibet in qua Sol nec[195] est in auge nec in eius opposito alibi incipit[196] quam incipiat arcus zodiaci qui motui Solis vere pro eiusdem diei principio correspondet. Et per coniunctionis primo arcui correspondet alia ascensio quam secundo cum iste modus operandi precedit, ac si ascensiones illorum arcuum essent eedem.[197] Ut igitur precise inveniatur differentiam ex ambabus causis simul resultans capiatur verus locus Solis per 18am huius tam pro principio diei de quo queris, quam pro fine eiusdem. Et arcus inter illa duo loca intercepti inveniatur ascensio que quidem ascensio est quantitas diei differentis, illa igitur si sit minor die medio subtrahatur ab eo, et si sit maior, subtrahatur ab ea dies medius et habebitur differentia quam inquiris. Si vero[198] fuerit equalis diei medio, tunc si dies differens qui proximo sequitur fuerit maior die medio ibi erit principium additionis et si fuerit minor ibi erit principium diminutionis, patet igitur tota coniunctio.

Et est notandum quod non oportet nec est verum omnes dies differentes maiores excedere tot dies medios per aggregatum ex maximis differentis causarum ambarum, vel omnes dies differentes minores per tantum excedi a tot diebus mediis, quia non in eodem loco quo est maxima differentia ex altera causa, est maxima differentia ex reliqua nec ab eodem puncto incipiunt additiones vel diminutiones unius cause et alterius. Immo altera causa incipit minuere antequam reliqua ad maximam sue augmentationis devenerit[199] et ideo ponit Ptholomeus[200] quod ubi est maxima additio[201] **[fol. 85r]** similiter vel maxima diminutio in diebus a meridie incoatis ibi differentia ex inequalitate motus Solis causata est 3 gradus et due tertie unius gradus et differentia ex inequalitate ascensionum proveniens que ibidem est maxima. Est ut ipse dicit 4

191 Si autem differentiam … dies differens diei mediocris] paraphrase of *Almagesti minor,* III.24.

192 alibi incipit *add. et del.* D_1.

193 zodiaci] *s.l.* D_1.

194 cuiuslibet … incipiat] *marg.* D_1.

195 nec] *iter. et del.* D_2.

196 incipit] *s. l.* D_2| *om.* D_1.

197 Nota modum prime operandi] *marg. per Ludowicum de Caerleon'* D_2.

198 fol. 38r, D_1.

199 immo … devenerit] *marg.* D_1.

200 Tholomeus D_1.

201 fol. 85r D_2.

gradus et due tertie fere quia est 4 gradus et 44 minuta secundum tabulas suas. Aggregatum igitur ex illis duobus differentiis est 8 gradus et tertia pars unius gradus, per quod omnes[202] maximi dies differentes secundum enim superant tot dies mediocres cui quidem aggregato, dimidium hore et pars eius 18a correspondet, propter hoc quod in una hora gradus 15 oriuntur hec autem quantitas temporis[203] cum dimissa fuerit in Sole et in stellis aliis non eveniet, ut dicit Ptholomeus[204] propter eius dimissionem quantitas sensibilis in inquisitione eorum in aliquo eorum que videntur. In Luna autem, propter velocitatem sui cursus, erit diversitas manifesta sensibilis eo quod quandoque in tanto tempore pretransit fere tertiam partem gradus. Est autem[205] unum aliud diligenter notandum[206] quod omnes dies differentes maiores simul sumpti non semper per equalem excessum[207] excedent tot dies medios nec semper in eodem puncto erit initium additionis sive initium diminutionis, neque semper eidem loco Solis sive in eccentrico sumatur[208] sive in zodiaco correspondet in diversis annis dies differentes equales. Sed per diuturnum processum temporis accidet variatio in singulis predictorum, cum eum per motum octave spere varietur distantia inter punctum equinoctii et longitudinem quamcumque eccentrici at differentiam diei differentis ad medium ex inequalitate motus Solis causata respectum habet ad distantiam Solis a longitudine media et in variatione eam consequitur, differentia vero ex inequalitate ascensionum proveniens habet respectum ad Solis distantiam a puncto equinoctii. Ideo oportet ut ex variatione distantie inter longitudinem mediam et punctum equinoctii, contingat variatio in predictis. Et ideo tabula Albategni[209] facta pro equatione dierum non potest esse perpetua, immo per lapsum temporis erit falsa.[210]

< [*D*1, fols. 38r–v] Docebo tamen tabulam unam componere, que una cum tabula ascensionum in circulo directo, pro diebus equandis deserviet in eternam.[211] Extendatur enim linea numeri usque ad 360 gradus per singulas unitates et erit primus gradus linee numeri gradus in mediate subsequens gradum illum in quo est longitudo media illa scilicet a qua recedit Sol ab opposito augis et accedit ad augem. Et ideo ut prompte sciatur quantum distinctum ille primus gradus linee numeri ab augis opposito, ponantur < numerus > illius[212] in capite tabule supra unitatem in linea numeri, vel in directo unitatis ex parte sinistra, ut verbi gratia. Arcus maxime equationis Solis secundum

[202] omnes] *supra lineam* D_1.

[203] ut dicit Tholomeus *add. et del.* D_1.

[204] ut dicit Tholomeus] *marg.* D_1.

[205] autem] etiam D_1.

[206] non semper per equalem excessum suum *add. et del.* D_1.

[207] excessum] *s. l.* D_1.

[208] summatur] *supra lineam* D_1.

[209] See al-Battānī's *De scientia stellarum,* chapter 29; the table is included in the Toledan tables.

[210] per lapsum temporis erit falsa] inD_2, here ends chapter 23. The section beginning with 'Docebo tamen tabulam unam componere' and ending 'dies diffeerentes pertransitionis predicte' is only displayed in D_1, despite Simon Bredon having deleted it with the note 'vacat'. See note below.

[211] Docebo … pertransitionis predicte] *add. et del.* D_1. A whole section was erased by Simon Bredon (D_1, fols. 38r-v) by the mention 'vacat' in margin. It was not included by Lewis Caerleon, who follows the text carefully and begins with Book III, 25 as Simon wished. The section removed by Simon Bredon begins with 'Docebo tamen tabulam unam componere …'.

[212] numerus illius …] *marg.* D_1.

Tholomeum est 2 gradus 23 minuta ut patent in 12 huius ideo illo subtracto a 90 gradibus, remanent 87 gradus 37 minuta, que est distantia longitudinis medie ab opposito augis Solis. Et quia in illa distantia Solis non variatur in subsequentis equatio Solis ab sinus equatione in distantia gradus in linea numeri ex parte sinistra vel supra capud eius subtrantur 88 gradus denotantes quod primus gradus linee numeri est 89 gradus ab opposito augis Solis.

Deinde in tabula equationis Solis inquiratur equatio Solis in eius distantia ab opposito augis per 89 gradus. Et si illa equatio sit equalis equationi maxime sed contiget propter permutationem distantie a longitudine media. Ponatur unus gradus in directo unitatis in proxima linea ex parte dextra, quia tantus est motus Solis veris in pertransitione 89 gradus ab opposito augis sumpti, et in eius directo, in linea tertia, ponatur cifra denotans quia nulla est differentia ter medium motum Solis et verum in pertransitione illius gradus.[213]

Postea consimiliter inquiratur equatio Solis in distantia 90 graduum ab opposito augis, et illa subtracta ab equatione maxima, si sit minor ea. Ponatur residuum in tertia linea in directo binarii, illo quia residuo a duobus gradibus subtracto, quod inde remanserit ponatur in subsequente linea in directo binarii, quia ille est motus Solis verus in pertransitione eius a principio 89 gradus usque ad finem gradus 90, ab opposito augis sumptorum.

Consimiliter procedendum est ulterius conversique devitatum fuerit ad augem, quod continget in directo 92 in linea numeri, ibi igitur quia nulla est equatio. Ponatur maxima equatio in tertia linea in directo 92, in linea numeri ibi igitur quia nulla est equatio ponatur maxima equatio in tertia linea in directo 92, illa que subtracta a 92 gradibus, ponatur residuum in subsequente linea in directo eorumdem 92 graduum qui est quantitas veri motus Solis a principio 89 gradus ab opposito augis usque ad augem, et illa maxima equatio posita in tertia linea est differentia per quam medius Solis motus in pertransitione predicta superat motum verum.

Deinde sumptis equationibus ab auge Solis usque ad eius oppositum, singule ad equationem maximam sunt addende. Et ponendum est aggregatum in directo graduum prout continget, qui illud erit differentia inter motum Solis verum et medium in pertransitione eius a predicta longitudine media ad locum illum. Subtracta que illa differentia a tot gradibus in quot graduum directo ponetur. Ponatur residuum in subsequente linea in directo graduum predictorum.

Deinde in processu ab opposito augis ad illam longitudinem mediam a qua fuit inceptio. Operandum est per subtractionem equationum ab equatione maximam scilicet operabatur in processu ab illa longitudine media ad augem. Et sic compositio dicte tabule †contineatur† ut igitur per dictam tabulam operemus, sic Sol gratia exempli in fine alicuius graduum linee numeri predictorum, et[214] numerus in subsequente linea in directo illius gradus inventus. Additur ad numerum per quem 89^{us} gradus[215] ab opposito augis distat a puncto equinoctii proximo precedentis illum 89um gradum,[216]

[213] A whole passage was crossed out by Simon Bredon and is now barely legible, it begins with: ‘Si vero differentia equatio…’.

[214] capi *add. et del.* D_1.

[215] a longitudine propriori *add. et del.* D_1.

[216] illum … gradum] *marg.* D_1.

scilicet a primo puncto Arietis vel Libre, et tam totius aggregati quam predicte distantie queratur ascensio in circulo directo subtracta igitur minori ascensione de maior remanebit quantitas temporis[217] direum differentium in pertransitione Solis a principio 89 gradus ab oppositione augis usque ad locum pro quo operati fuerimus transactorum, per cuius relationem ad tempus dierum mediocrum[218] in pertransitione[219] habebitur differentia inter dies mediocres et dies differentes pertransitionis predicte. >

24. Dies mediocres in dies differentes convertire et econtra.

Tam propter principium[220] propositi temporis quam propter finem eiusdem[221] inveniatur uterque motus Solis scilicet verus et medius, et subtracto medio motu Solis pro principio illius temporis a motu eius medio pro fine eiusdem, servetur residuum. Item subtracto vero motu Solis pro principio predicti temporis a vero motu eius pro fine ipsius residui queratur ascensio in circulo directo.

Si a meridiano dies inceperis[222] vel in **[fol. 85v]** circulo obliquo si dies ab orizonte incoaveris[223] et si dicta ascensio minor fuerit motu medio preservato, subtrahatur ab eo deinde resoluta differentia in partes horarum sumendo semper pro uno gradu 4 minuta hore que sunt 15a pars illius patet quod per partes horarum[224] correspondentes dicte differentie terminabuntur autem finem propositi temporis tot dies differentes quot fuerant in proposito tempore mediocres, et ideo ubi dies differentes sunt[225] per certam differentiam diebus mediis breviores. Addenda est illa differentia ad numerum dierum mediorum denotans quod illi numero dierum mediocrum correspondent tot dies differentes et differentia tanta ulterius. Si vero ascensio predicta maior fuerit motu medio preservato, subtrahatur medius motus ab ea et tempus remanenti differentie correspondens subtrahendum est a numero dierum mediorum propositi temporis, denotans quod diebus mediocribus temporis propositi non correspondent tot dies differentes. Sed numerus per differentiam antedictam.

Iste igitur est modus convertendi dies mediocres in dies differentes, quod si volueris econtra convertere, operaberis econverso.

Et est notandum quod per istum modum precisissime fieri patet tabula equationis dierum que licet non poterit esse perpetua, operando tamen cum ea per 100 annos insensibilis erit error.

Inquiratur igitur in linea numeri tabule equationis Solis, gradus correspondens 18 gradui Aquarii, eo quod a principio illius gradus incipit: dies differens esse minor die mediocri ex causa inequalitatis[226] ascensionis, ut probari potest per eam[227] que dixi

217 *s.l.* D_1.

218 qui fuerit *add. et del.* D_1.

219 several deleted words D_1.

220 principium] principio D_1.

221 eiusdem] *s.l.* D_1.

222 Two illegible words erased after *dies* and *inceperis* D_1.

223 inquoaveris D_1.

224 dicte differentie *add. et del.* D_1.

225 *s. l.* D_1.

226 inequalitatis] *marg.* D_1.

227 per ea D_1, D_2.

in 21 huius, quo gradu[228] invento per equationes principium et finis illius inveniatur arcus veri motus Solis in pertransitione illius gradus, deinde illius arcus veri motus queratur ascensio in circulo directo que si sit unus gradus precise erit, ibidem[229] quantitas diei differentis equalis quantitati diei mediocris, et ideo[230] erit ibidem inceptio additionis, et ideo ponatur ibi cifra in directo 18 gradus Aquarii denotans quod nulla differentia erit ibi.[231] Si vero illa ascensio fuerit maior uno gradu, inquiratur ascensio veri motus Solis correspondentis pertransitioni gradus subsequentis, nec cesses quousque deveneris ad ascensionem que precise continet unum gradum, ut ibidem additionis principium habeatur. Illo igitur gradu invento, inquiratur verus motus Solis correspondens pertransitioni duorum[232] graduum coniunctioni illius scilicet et gradus subsequentis, et illius veri motus ascensione a duobus[233] gradibus subtracta. Ponatur differentia in directo gradus subsequentis.

Deinde invento vero motu Solis correspondente pretransitioni trium graduum simul iunctorum[234] scilicet secundorum[235] predictorum et tertii subsequentis. Subtrahatur eius ascensio a tribus gradibus et ponatur differentia econtra gradum tertium subsequentem et per istum modum procedas ulterius **[fol. 86r]** usque ad totius circuli complementum, et sicut patet compositio tabule antedicte. Si igitur radices[236] motuum posite fuerit super principium additionis in tabula scilicet ubi dies medii inceperunt esse mariores diebus differentibus[237] tunc differentiam quelibet ibi inventa. Addenda est continue, ut dies differentes ex diebus mediis habeantur.

Si tamen ponerentur radices super principium diminutionis, tunc esset differentia quelibet[238] inventa in tabula minuenda.[239] Et est hic unum diligenter, notandum quod si radices alique, que nec sunt super principium additionis,[240] nec super principium diminutionis in tabula posite fuerint sine equationem dierum, ut puta per solam additionem ad loca instrumentaliter ad inventa vel per subtractionem ab eisdem secundum correspondentiam temporis mediocris inter instans considerationis instrumentalis et radicis principium intercepti, prout docet Ptholomeus[241] in 18a huius et prout etiam patet per radices positas in directo annorum quorumlibet collectorum. Tunc cum indiguerimus equatione dierum nec poterimus eos equare per hanc tabulam neque per regulam prius tactam, tabula enim non sufficet eo quod illa docet semper addere

228 inveniatur *add. et del. D1.*

229 tempus motus solis *add. et del. D1.*

230 ideo] *add. D2.*

231 ibi] ibidem *D1.*

232 2orum *D2.*

233 2bus *D2.*

234 iunctorum] simul *D1.*

235 2orum *D2.*

236 tempore *add. et del. D1.*

237 ubi dies … differentibus] *marg. D1.*

238 in *add. et del. D2.*

239 si tunc … tabula minuenda] *marg. D1.*

240 Nota] *marg. per Ludowicum de Caerleon D2.*

241 Tholomeus *D1.*

cum tamen dies differentes aliquando addunt super dies medios et aliquando minuunt ab eisdem. Nec operari poterimus per regulam supradictam, illa enim requirit, ut habeatur noticia initii diei super quem ponuntur radices, ita videlicet ut ponantur radices super verum initium illius diei sive ab orizonte sive a meridie incoetur[242] vel ut ponantur super instans cuius distantia a vero initio illius diei nullatenus ignoretur. Si igitur per dictam regulam equanti sunt dies pro motibus inquirendis, oportet quod secundum modum predictum radices illorum motuum sunt equate. Et si per dictam tabulam voluerimus operari tunc radices motuum[243] de quibus agemus, non erunt super veram meridiem diei super quem ponentur. Sed videndum est in dicta tabula equationis dierum quanta equatio temporis correspondeat illi diei super quem ponentur radices, et ulterius videndum est quantus est motus illius planete cuius habenda est radix illi tempori correspondens. Deinde addito tanto motu loco illius planete in meridie dicti diei, resultabit radix motus eiusdem planete cum qua quidem radice operabimus, si pro motu habendo illius planete dies predictam tabulam fuit equandi.

Non igitur in isto opere erunt radices super veram meridiem illius diei super quem ponentur, sed super meridiem mediam. Meridiem scilicet per tantum sequentem meridiem veram per quantum omnes dies medii intercepti inter diem illum et diem a quo sit initium additionis in tabula simul sumpti excedunt omnes dies differentes eiusdem temporis simul sumptos. Unde inventa radice aliqua per hunc modum que scilicet intitulata est super meridiem dicto modo mediam alicuius diei, et non super meridiem eius, veram per solam additionem ad illam radicem vel per solam subtractionem ab ea secundum correspondentiam temporis iuxta doctrinam 18e huius haberi possunt radices ad quoscumque annos collectos, menses et dies, nec non et ad sectas cognitas qualescumque **[fol. 86v]** ita quod per quamlibet huius radicum inveniri potest locus planete cuius sunt radices ad quodcumque tempus quod equandi fuerit per tabulam antedictam.[244] Consimiliter coniunctiones et oppositiones radicales computande sunt secundum notam distantiam a meridie media diei super quem ponentur et non secundum distantiam a vera eius meridie. Si pro coniunctionibus vel oppositionibus habendis equandi sunt dies per tabulam hanc pretactam.[245] Sic igitur sufficient patet modus equandi dies tam per tabulam quam per regulam supradictam. Hic inferit Ptholomeus[246] ea que sequuntur dicens fuit autem locus in quo fuit Solis secundum computationem nostram in principio annorum Nabugodonosor in primo die mensis tantum qui est ex mensibus Egyptorum[247] in media die per motum eius medium, sicut iam ostendimus ante, scilicet, capitulo 2° et 8° huius[248] in 45to minuto prime partis Piscis et per motum suum diversum in tertia parte et octavo minuto Piscis fere.

[242] inquoetur *D1.*

[243] Fol. 39r *D1.*

[244] unde … tabulam antedictam] *marg. D1.*

[245] pre [*add et del.*] tactam *D2.*

[246] Tholomeus *D1.*

[247] Egiptorum *D1*; *D2.*

[248] huius] huius parum *D1.*

Cum addideris super annos Gerdagird et menses et dies eius 955 annos et tres menses erunt qui provenerint anni Alexandri per quos intrabis in canone Zeum[249] Alexandrini. Et cum addideris annis Gerdagird et mensibus eius et diebus 1379 annos et tres menses erunt qui provenerunt anni Nabugodonosor qui sicut per quos intrabis in hunc librum.[250]

Appendix C. Comparison between Lewis Caerleon's canons and Simon Bredon's *Commentum super Almagesti,* III.22–24

Lewis Caerleon, *Canones equationis dierum*	Simon Bredon, *Commentum super Almagesti*
Non tamen oportet, nec est verum, omnes dies differentes minores per tantum excedi a tot diebus mediis, scilicet, per aggregatum ex magnis differentis causarum ambarum. Quia non in eodem loco quo est maxima differentia ex altera causa est maxima differentia ex reliqua, nec ab eodem puncto incipiunt additiones vel diminutiones unius cause et alterius…	Et est notandum quod non oportet, nec est verum, omnes dies differentes maiores excedere tot dies medios per aggregatum ex maximis differentis causarum ambarum vel omnes dies differentes minores per tantum excedi a tot diebus mediis. Quia non in eodem loco quo est maxima differentia ex altera causa, est maxima differentia ex reliqua nec ab eodem puncto incipiunt additiones vel diminutiones unius cause et alterius… [Simon Bredon, III,23]
Ymo altera causa incipit minuere antequam reliqua ad maximam sue augmentationis devenerit propter motum augis. Et ideo, non semper invenitur maxima equatio dierum seu differentia ex ambabus causis simul una et eadem et equaliter propter variationem augis Solis, ut patet in tabulis. Quia Azarchel invenit maximam differentiam ex utraque causa simul in tempore suo 7 gradus et 54 minuta, Albategni vero 7 gradus et 57 minuta, ego vero in diebus meis supponendo augem Solis in primo gradu Cancri perfecto inveni maximam differentiam ex utraque causa simul 8 gradus, 12 minuta et 30 secunda, precise operando quod est prope positionem Ptholomei…	Immo altera causa incipit minuere antequam reliqua ad maximam sue augmentationis devenerit et ideo ponit Ptholomeus… [Simon Bredon, III,23]

249 Zeid Alexandrini D_2. The same misspelling of Theo is found in both witnesses, i.e.: Theon of Alexandria.

250 Both manuscripts display a table of epochs.

Lewis Caerleon, *Canones equationis dierum*	Simon Bredon, *Commentum super Almagesti*
Ego vero ponam unum modum lenem per quem precissime fieri potest tabula equationis dierum, ut ego feci qualicet vero potit esse perpetua, operando tamen cum ea per 100 vel 200 annos, insensibilis erit error Suppone Solem secundum medium cursum in 18 gradu Aquarii, eo quod a principio illius gradus secundum verum motum incipit dies differens esse minor die mediocri ex causa inequalitatis ascensionum, ut patet in tabulis ascensionum circuli directi…	Et est notandum quod per istum modum precissime fieri patet tabula equationis dierum que licet non poterit esse perpetua operando tum cum ea per 100 annos insensibilis erit error inquiratur igitur in linea numeri tabule equationis Solis gradus correspondens 18 gradui Aquarii, eo quod a principio illius gradus incipit dies differens esse minor die mediocri ex causa inequalitatis ascensionis… [Simon Bredon, III,25]
Et ideo erit ibidem inceptio additionis et ideo ponuntur illi cifra in directo illius gradus Aquarii veri motus Si vero illa ascensio fuerit maior uno gradu, inquiratur ascensio veri motus Solis correspondentis pertransitioni gradus subsequentis medii motus, nec cesses consequensque deveneris ad ascensionem arcus veri motus que precise continet unium gradum, ut ibidem additionis principium habetur Illo igitur gradu invento inquiratur verus motus Solis correspondens pertransitioni duorum graduum coniunctioni illius, scilicet, et gradus subsequentis et illius veri motus ascensione a duobus gradibus, subtracta ponatur differentia in directo gradus subsequentis Deinde invento vero motu Solis correspondente pertransitioni 3 graduum simul iunctorum scilicet duorum predictorum et tertii subsequentis subtrahatur eius ascensio a tribus gradibus medii motus et ponatur differentia contra gradum tertium subsequentem, et per istum modum procedas ulterius usque ad totius circuli complementum	Et ideo erit ibidem inceptio additionis, et ideo ponatur ibi cifra in directo 18 gradus Aquarii denotans quod nulla differentia erit ibi Si vero illa ascensio fuerit maior, uno gradu inquiratur ascensio veri motus Solis correspondentis pertransitioni gradus subsequentis, nec cesses quousque deveneris ad ascensionem que precise continet unium gradum, ut ibidem additionis principium habeatur Illo igitur gradu invento inquiratur verus motus Solis correspondens pertransitioni duorum graduum coniunctioni illius scilicet et gradus subsequentis et illius veri motus ascensione a duobus gradibus subtracta. Ponatur differentia in directo gradus subsequentis Deinde invento vero motu Soli correspondente pretransitioni trium graduum simul iunctorum scilicet secundorum predictorum et tertii subsequentis subtrahatur eius ascensio a tribus gradibus et ponatur differentia econtra gradum terctium subsequentem et per istum modum procedas ulterius usque ad totius circuli complementum, et sicut patet compositio tabule antedicte… [Simon Bredon, III,25]
Si igitur radices motuum posite fuerint super principium additionis in tabula, scilicet, veri dies medii incipiunt esse maiores diebus differentibus, scilicet, in predicto gradu Aquarii tunc differentia quelibet ibi inventa addenda est continue, ut dies differentes ex diebus mediis habentur Si tamen ponerentur radices super principium diminutionis tunc esset differentia quelibet inventa in tabula numeranda de diebus mediis	Si igitur radices motuum posite fuerit super principium additionis in tabula scilicet ubi dies medii inceperunt esse mariores diebus differentibus tunc differentiam quemlibet ibi inventa. Addenda est continue ut dies differentes ex diebus mediis habeantur Si tamen ponerentur radices super principium diminutionis, tunc esset differentia quelibet inventa in tabula minuenda [Simon Bredon, III,25]

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